

APPENDIX G

**STATISTICAL AND GEOCHEMICAL EVALUATIONS
OF SITE METALS DATA**

STATISTICAL

Statistical Comparison of Site and Background Data Former Rifle/Machine Gun Ranges (Firing Line Areas), Parcels 100Q and 101Q Fort McClellan, Alabama

1.0 Introduction

This report provides the Tier 1 and Tier 2 (Shaw E&I, 2003) site-to-background comparison results for the Former Rifle/Machine Gun Ranges (Firing Line Areas), Parcels 100Q and 101Q, Fort McClellan, in Calhoun County, Alabama. In the first step of the comparison, the maximum detected concentration (MDC) of each element is compared to two times the arithmetic mean of the background data (SAIC, 1998). Any metal that has an MDC greater than the background screening value is carried forward for Tier 2 evaluation, which includes the Slippage Test and the Wilcoxon Rank Sum Test (WRS). If either or both of these statistical tests cannot be done, the evaluation will include the Hot Measurement Test.

The methodology and results of the Tier 1 and Tier 2 comparisons are summarized in Tables 1 through 5, and described in more detail in the following sections. Site samples used in the site-to-background comparison include 21 surface soil samples (0 to 1 foot below ground surface [bgs]), 21 subsurface soil samples (3 to 4 feet bgs), 3 groundwater samples, 3 sediment sample, and 3 surface water sample that were collected at the site.

Background distributions and screening values have been established for target analyte list metals in surface soil, subsurface soil, groundwater, sediment, and surface water for Fort McClellan (SAIC, 1998).

2.0 Comparison Methodology

This section describes the statistical techniques that were employed in the Former Rifle/Machine Gun Ranges (Firing Line Areas), Parcels 100Q and 101Q site-to-background comparisons.

2.1 Statistical Procedures

Contamination can be caused by a variety of processes that yield different spatial distributions of elevated contaminant concentrations. Slight but pervasive contamination can occur from non-point-source releases, and can result in slight increases in contaminant concentrations in a large percentage of samples. Localized, or “hot-spot,” contamination can result in elevated concentrations in a small percentage of the total number of site samples. No single two-sample

Table 1

Summary of Tier 1 and Tier 2 Site to Background Comparison for Surface Soil
Former Rifle/Machine Gun Ranges (Firing Line Areas), Parcels 100Q and 101Q
Fort McClellan, Calhoun County, Alabama

Metals	Frequency of Detection	Tier 1 Evaluation ^a	Slippage Test ^b	Wilcoxon Rank Sum Test ^b	Hot Measurement Test ^{b,c}	Carried Forward for Tier 3 Geochemical Evaluation
Aluminum	21 / 21	Failed	Passed	Failed	NA	Yes
Antimony	0 / 21	NA	NA	NA	NA	
Arsenic	21 / 21	Passed	NA	NA	NA	
Barium	21 / 21	Failed	Passed	Failed	NA	Yes
Beryllium	19 / 21	Failed	Failed	Failed	NA	Yes
Cadmium	0 / 21	NA	NA	NA	NA	
Calcium	21 / 21	Passed	NA	NA	NA	
Chromium	21 / 21	Passed	NA	NA	NA	
Cobalt	21 / 21	Failed	Passed	Failed	NA	Yes
Copper	21 / 21	Failed	Failed	Failed	NA	Yes
Iron	21 / 21	Failed	Passed	Failed	NA	Yes
Lead	21 / 21	Failed	Failed	Failed	NA	Yes
Magnesium	21 / 21	Failed	Passed	Failed	NA	Yes
Manganese	21 / 21	Failed	Passed	Failed	NA	Yes
Mercury	17 / 21	Failed	Passed	NA ^d	Failed	Yes
Nickel	21 / 21	Failed	Passed	Failed	NA	Yes
Potassium	21 / 21	Failed	Passed	Failed	NA	Yes
Selenium	1 / 21	Failed	Passed	NA ^d	Failed	Yes
Silver	2 / 21	Failed	Passed	NA ^d	Failed	Yes
Sodium	21 / 21	Passed	NA	NA	NA	
Thallium	0 / 21	NA	NA	NA	NA	
Vanadium	21 / 21	Failed	Passed	Failed	NA	Yes
Zinc	21 / 21	Failed	Passed	Failed	NA	Yes

NA = not applicable; MDC = maximum detected concentration; UTL = upper tolerance limit

a Tier 1 evaluation (site MDC compared to 2 x the background mean) per **Selecting Site-Related Chemicals for Human Health and Ecological Risk Assessments for FTMC, Revision 2**, Technical Memorandum, 24 June 2003 by Paul Goetchius.

b Part of Tier 2 evaluation per the above referenced memo.

c Performed only when the Slippage test and/or WRS test cannot be performed.

d WRS test is not performed on data sets containing 50% or more nondetects.

Table 2

**Summary of Tier 1 and Tier 2 Site to Background Comparison for Subsurface Soil
Former Rifle/Machine Gun Ranges (Firing Line Areas), Parcels 100Q and 101Q
Fort McClellan, Calhoun County, Alabama**

Metals	Frequency of Detection	Tier 1 Evaluation ^a	Slippage Test ^b	Wilcoxon Rank Sum Test ^b	Hot Measurement Test ^{b,c}	Carried Forward for Tier 3 Geochemical Evaluation
Aluminum	21 / 21	Failed	Passed	Failed	NA	Yes
Antimony	0 / 21	NA	NA	NA	NA	
Arsenic	21 / 21	Failed	Passed	Passed	NA	
Barium	21 / 21	Failed	Passed	Failed	NA	Yes
Beryllium	19 / 21	Failed	Passed	Failed	NA	Yes
Cadmium	0 / 21	NA	NA	NA	NA	
Calcium	21 / 21	Passed	NA	NA	NA	
Chromium	21 / 21	Passed	NA	NA	NA	
Cobalt	21 / 21	Failed	Passed	Failed	NA	Yes
Copper	21 / 21	Passed	NA	NA	NA	
Iron	21 / 21	Failed	Passed	Passed	NA	
Lead	21 / 21	Failed	Passed	Failed	NA	Yes
Magnesium	21 / 21	Failed	Passed	Failed	NA	Yes
Manganese	21 / 21	Failed	Passed	Failed	NA	Yes
Mercury	18 / 21	Failed	Passed	NA ^e	Failed	Yes
Nickel	21 / 21	Failed	Passed	Failed	NA	Yes
Potassium	21 / 21	Failed	Passed	Failed	NA	Yes
Selenium	6 / 21	Failed	NA ^d	NA ^e	Failed	Yes
Silver	6 / 21	Failed	NA ^d	NA ^e	Failed	Yes
Sodium	21 / 21	Passed	NA	NA	NA	
Thallium	0 / 21	NA	NA	NA	NA	
Vanadium	21 / 21	Passed	NA	NA	NA	
Zinc	21 / 21	Failed	Passed	Failed	NA	Yes

NA = not applicable; MDC = maximum detected concentration; UTL = upper tolerance limit

a Tier 1 evaluation per **Selecting Site-Related Chemicals for Human Health and Ecological Risk Assessments for FTMC, Revision 2**, Technical Memorandum, 24 June 2003 by Paul Goetchius.

b Part of Tier 2 evaluation per the above referenced memo.

c Performed only when the Slippage test and/or WRS test cannot be performed.

d Slippage test is not performed on data sets for which the maximum background value is a nondetect.

e WRS test is not performed on data sets containing 50% or more nondetects.

Table 3

**Summary of Tier 1 and Tier 2 Site to Background Comparison for Groundwater
Former Rifle/Machine Gun Ranges (Firing Line Areas), Parcels 100Q and 101Q
Fort McClellan, Calhoun County, Alabama**

Metals	Frequency of Detection	Tier 1 Evaluation ^a	Slippage Test ^b	Wilcoxon Rank Sum Test ^b	Hot Measurement Test ^{b,c}	Carried Forward for Tier 3 Geochemical Evaluation
Aluminum	2 / 3	Passed	NA	NA	NA	
Antimony	0 / 3	NA	NA	NA	NA	
Arsenic	0 / 3	NA	NA	NA	NA	
Barium	2 / 3	Passed	NA	NA	NA	
Beryllium	0 / 3	NA	NA	NA	NA	
Cadmium	0 / 3	NA	NA	NA	NA	
Calcium	2 / 3	Passed	NA	NA	NA	
Chromium	0 / 3	NA	NA	NA	NA	
Cobalt	2 / 3	Passed	NA	NA	NA	
Copper	0 / 3	NA	NA	NA	NA	
Iron	3 / 3	Passed	NA	NA	NA	
Lead	0 / 3	NA	NA	NA	NA	
Magnesium	3 / 3	Passed	NA	NA	NA	
Manganese	3 / 3	Passed	NA	NA	NA	
Mercury	0 / 3	NA	NA	NA	NA	
Nickel	0 / 3	NA	NA	NA	NA	
Potassium	1 / 3	Passed	NA	NA	NA	
Selenium	0 / 3	NA	NA	NA	NA	
Silver	0 / 3	NA	NA	NA	NA	
Sodium	2 / 3	Passed	NA	NA	NA	
Thallium	0 / 3	NA	NA	NA	NA	
Vanadium	0 / 3	NA	NA	NA	NA	
Zinc	0 / 3	Passed	NA	NA	NA	

NA = not applicable; MDC = maximum detected concentration; UTL = upper tolerance limit

a Tier 1 evaluation per **Selecting Site-Related Chemicals for Human Health and Ecological Risk Assessments for FTMC, Revision 2**, Technical Memorandum, 24 June 2003 by Paul Goetchius.

b Part of Tier 2 evaluation per the above referenced memo.

c Performed only when the Slippage test and/or WRS test cannot be performed.

Table 4

**Summary of Tier 1 and Tier 2 Site to Background Comparison for Sediment
Former Rifle/Machine Gun Ranges (Firing Line Areas), Parcels 100Q and 101Q
Fort McClellan, Calhoun County, Alabama**

Metals	Frequency of Detection	Tier 1 Evaluation ^a	Slippage Test ^b	Wilcoxon Rank Sum Test ^b	Hot Measurement Test ^{b,c}	Carried Forward for Tier 3 Geochemical Evaluation
Aluminum	3 / 3	Failed	Passed	NA ^d	Failed	Yes
Antimony	0 / 3	NA	NA	NA	NA	
Arsenic	3 / 3	Passed	NA	NA	NA	
Barium	3 / 3	Failed	Passed	NA ^d	Passed	
Beryllium	3 / 3	Failed	Passed	NA ^d	Failed	Yes
Cadmium	0 / 3	NA	NA	NA	NA	
Calcium	3 / 3	Passed	NA	NA	NA	
Chromium	3 / 3	Passed	NA	NA	NA	
Cobalt	3 / 3	Passed	NA	NA	NA	
Copper	3 / 3	Failed	Passed	NA ^d	Failed	Yes
Iron	3 / 3	Passed	NA	NA	NA	
Lead	3 / 3	Failed	Passed	NA ^d	Failed	Yes
Magnesium	3 / 3	Passed	NA	NA	NA	
Manganese	3 / 3	Failed	Passed	NA ^d	Passed	
Mercury	3 / 3	Passed	NA	NA	NA	
Nickel	3 / 3	Failed	Passed	NA ^d	Passed	
Potassium	3 / 3	Passed	NA	NA	NA	
Selenium	0 / 3	NA	NA	NA	NA	
Silver	0 / 3	NA	NA	NA	NA	
Sodium	3 / 3	Passed	NA	NA	NA	
Thallium	0 / 3	NA	NA	NA	NA	
Vanadium	3 / 3	Passed	NA	NA	NA	
Zinc	3 / 3	Passed	NA	NA	NA	

NA = not applicable; MDC = maximum detected concentration; UTL = upper tolerance limit

^a Tier 1 evaluation per **Selecting Site-Related Chemicals for Human Health and Ecological Risk Assessments for FTMC, Revision 2**, Technical Memorandum, 24 June 2003 by Paul Goetchius.

^b Part of Tier 2 evaluation per the above referenced memo.

^c Performed only when the Slippage test and/or WRS test cannot be performed.

^d WRS test is not performed on data sets with sample sizes less than 5.

Table 5

**Summary of Tier 1 and Tier 2 Site to Background Comparison for Surface Water
Former Rifle/Machine Gun Ranges (Firing Line Areas), Parcels 100Q and 101Q
Fort McClellan, Calhoun County, Alabama**

Metals	Frequency of Detection	Tier 1 Evaluation ^a	Slippage Test ^b	Wilcoxon Rank Sum Test ^b	Hot Measurement Test ^{b,c}	Carried Forward for Tier 3 Geochemical Evaluation
Aluminum	3 / 3	Passed	NA	NA	NA	
Antimony	0 / 3	NA	NA	NA	NA	
Arsenic	0 / 3	NA	NA	NA	NA	
Barium	3 / 3	Passed	NA	NA	NA	
Beryllium	0 / 3	NA	NA	NA	NA	
Cadmium	0 / 3	NA	NA	NA	NA	
Calcium	3 / 3	Passed	NA	NA	NA	
Chromium	0 / 3	NA	NA	NA	NA	
Cobalt	0 / 3	NA	NA	NA	NA	
Copper	1 / 3	Passed	NA	NA	NA	
Iron	3 / 3	Passed	NA	NA	NA	
Lead	1 / 3	Passed	NA	NA	NA	
Magnesium	3 / 3	Passed	NA	NA	NA	
Manganese	3 / 3	Passed	NA	NA	NA	
Mercury	0 / 3	NA	NA	NA	NA	
Nickel	0 / 3	NA	NA	NA	NA	
Potassium	0 / 3	NA	NA	NA	NA	
Selenium	0 / 3	NA	NA	NA	NA	
Silver	0 / 3	NA	NA	NA	NA	
Sodium	3 / 3	Passed	NA	NA	NA	
Thallium	0 / 3	NA	NA	NA	NA	
Vanadium	0 / 3	NA	NA	NA	NA	
Zinc	0 / 3	NA	NA	NA	NA	

NA = not applicable

a Tier 1 evaluation per *Selecting Site-Related Chemicals for Human Health and Ecological Risk Assessments for FTMC, Revision 2*, Technical Memorandum, 24 June 2003 by Paul Goetchius.

b Part of Tier 2 evaluation per the above referenced memo.

c Performed only when the Slippage test and/or WRS test cannot be performed.

statistical comparison test is sensitive to both of these modes of contamination. For this reason, the use of several simultaneous tests is recommended for a valid and complete comparison of site versus background distributions (U.S. Environmental Protection Agency [EPA], 1989, 1992, and 1994; U.S. Navy, 2002).

Analytes that fail the Tier 1 and Tier 2 comparisons are subject to a geochemical evaluation to determine if the elevated concentrations are due to natural processes or if they represent potential contamination.

2.1.1 Tier 1

In this step of the background screening process, MDC of the site data set is compared to the background screening value of two times the background mean (SAIC, 1998). Elements for which the site MDC does not exceed the background screening value are considered to be present at background concentrations, and are not considered site-related chemicals. Elements for which the site MDC exceeds the background screening value undergo further evaluation (Tier 2).

2.1.2 Tier 2

Slippage Test. The nonparametric Slippage test is designed to detect a difference between the upper tails of two distributions, and has been recommended for use in site-to-background comparisons to identify potential localized, or hot-spot, contamination (U.S. Navy, 2002). The test is performed by counting the number (K) of detected concentrations in the site data set that exceed the maximum background measurement, and then comparing this number to a critical value (K_c), which is a function of the number of background samples and the number of site samples. If $K > K_c$, then potential contamination is indicated and the analyte will be subjected to geochemical evaluation. If $K \leq K_c$, then localized contamination is not suspected.

Critical values tables for site and background data sets up to size $n = 50$ are provided in U.S. Navy (2002). Critical values for larger data sets are calculated using the test statistic provided in Rosenbaum (1954). In this report, the Slippage test is performed at the 95 percent confidence level. The test cannot be performed if the maximum background value is a nondetect, because the actual concentration in that sample is unknown.

Wilcoxon Rank Sum Test. The nonparametric WRS test is designed to detect a difference between the medians of two data sets, and has been recommended for use in site-to-background comparisons to identify slight but pervasive contamination (EPA, 2000; U.S. Navy, 2002). In

this report, the WRS test is performed when the site and background data sets each contain less than 50 percent nondetects (i.e., measurements reported as not detected below the laboratory reporting limit). The WRS test will not be performed on data sets containing 50 percent or more nondetects. The medians of such data sets are unknown, and hence the test results would lack sufficient power to yield reliable results.

The WRS test compares two data sets of size n and m ($n > m$), and tests the null hypothesis that the samples were drawn from populations with distributions having the same medians. To perform the test, the two sets of observations are pooled and arranged in order from smallest to largest. Each observation is assigned a rank; that is, the smallest is ranked 1, the next largest is ranked 2, and so on up to the largest observation, which is ranked $(n + m)$. If ties occur between or within samples, each one is assigned the mid-rank. Next, the sum of the ranks of smaller data set m is calculated. Then the test statistic Z is determined,

$$Z = \frac{W - m(m + n + 1)/2}{\sqrt{mn(m + n + 1)/12}}$$

Where:

- W = Sum of the ranks of the smaller data set
- m = Number of data points in smaller group
- n = Number of data points in larger group.

This test statistic Z is used to find the two-sided significance. For instance, if the test statistic yields a probability of a Type I error (p-level) less than 0.2, then there is a statistically significant difference between the medians at the 80 percent confidence level. A Type I error involves rejecting the null hypothesis when it is true. If the p-level is greater than 0.2, then there is no reasonable justification to reject the null hypothesis at the 80 percent confidence level. It can therefore be concluded that the medians of the two data sets are similar, and it can be assumed to be drawn from the same population.

If the p-level is less than 0.2, then the medians of the two distributions are significantly different at the 80 percent confidence level. This can occur if the site data are shifted higher or lower than the background data. If the site data are shifted higher relative to background, then contamination may be indicated, and the analyte in question will be carried on for geochemical evaluation; however, if the site data are shifted lower relative to background, then contamination

is not indicated. If the p-level is greater than 0.2, then pervasive site contamination is not suspected.

Box Plots. A quick, robust graphical method recommended by the EPA to visualize and compare two or more groups of data is the box plot comparison (EPA, 1989 and 1992). These plots provide a summary view of the entire data set, including the overall location and degree of symmetry. The box encloses the central 50 percent of the data points so that the top of the box represents the 75th percentile and the bottom of the box represents the 25th percentile. The small box within the larger box represents the median of the data set. The upper whisker extends outward from the box to the maximum point and the lower whisker extends to the minimum point. Nondetect results are set equal to one-half of the reporting limit for plotting purposes.

For each analyte, box plots of site and background data are placed side by side to visually compare the distributions and qualitatively determine whether the data sets are similar or distinct. Accordingly, the box plots are a necessary adjunct to the WRS test. As described previously, the WRS test may indicate that the medians of the site and background data sets are significantly different. Examination of the box plots will confirm whether that difference is caused by site data that are shifted higher or lower relative to background.

Hot Measurement Test. The hot measurement test consists of comparing each site measurement with a concentration value that is representative of the upper limit of the background distribution (EPA, 1994). Ideally, a site sample with a concentration above the background screening value would have a low probability of being a member of the background distribution, and may be an indicator of contamination. It is important to select such a background screening value carefully so that the probability of falsely identifying site samples as contaminated or uncontaminated is minimized.

The 95th upper tolerance limit (95th UTL) is recommended as a screening value for normally or lognormally distributed analytes and the 95th percentile is recommended as a screening value for nonparametrically distributed analytes (EPA, 1989, 1992, and 1994). Site samples with concentrations above these values are not necessarily contaminated, but should be considered suspect. To perform the test, each analyte's site MDC is compared to the background 95th UTL or 95th percentile, in accordance with the type of background distribution. If the site MDC exceeds the background screening value, then that analyte will undergo a geochemical evaluation. If the MDC does not exceed the background threshold value, then hot-spot contamination is not indicated.

2.1.3 Geochemical Evaluation

If an analyte fails either of the statistical tests described above, then a geochemical evaluation is performed to determine if the elevated concentrations are caused by natural processes. The methodology and results of the geochemical evaluation are provided in separately in this appendix.

3.0 Results of the Site-to-Background Comparisons

This section presents the results of the site-to-background comparisons for 23 TAL metals in the Parcels 100Q and 101Q soil, groundwater, sediment, and surface water samples. Tables 1 through 5 summarize the Tier 1 and Tier 2 test results for each media as discussed in the following sections. Slippage test results, WRS test results, and applicable Hot Measurement tests are discussed in detail below. The corresponding box plots are also discussed below and are provided in Attachment 1.

3.1 Surface Soil

Twenty-three TAL metals were evaluated in the surface soil samples from Parcels 100Q and 101Q. Antimony, cadmium, and thallium had no detected concentrations in surface soil, so these metals will not be discussed any further. Arsenic, calcium, chromium, and sodium had no detected concentrations above the background screening value, passing the Tier 1 evaluation. They will not be discussed any further.

The remaining 16 metals underwent Tier 2 evaluation. The statistical test results and box plots are discussed in detail below.

Table 1 summarizes the Tier 1 and Tier 2 test results for surface soil.

Aluminum

Tier 1 Evaluation

Ten site samples exceed the background screening value of 16,306 milligrams per kilogram (mg/kg).

Slippage Test

The critical value, K_c , for aluminum is 3. Aluminum has no samples exceeding the maximum background measurement ($K=0$). Because $K < K_c$ aluminum passes the Slippage test.

WRS Test

The WRS test p-level < 0.001 indicates a significant difference between the site and background distributions.

Box Plot

Box plots for the site and background data sets are provided in Figure 1-1. The site minimum and interquartile range are higher than that of background. The site maximum is lower than the corresponding background value.

Conclusion

Because aluminum in surface soil failed statistical comparison to background, it is carried forward for Tier 3 geochemical evaluation.

Barium

Tier 1 Evaluation

Two site samples exceed the background screening value of 123.94 mg/kg.

Slippage Test

K_c for barium is 3. No site samples exceed the maximum background measurement ($K=0$). Because $K < K_c$ barium passes the Slippage test.

WRS Test

The WRS test p-level of 0.002 indicates a significant difference between the site and background distributions.

Box Plot

The site minimum and interquartile range are higher than that of background (Figure 1-1). The site maximum is lower than the corresponding background value.

Conclusion

Because barium in surface soil failed statistical comparison to background, it is carried forward for Tier 3 geochemical evaluation.

Beryllium

Tier 1 Evaluation

Nine site samples exceed the background screening value of 0.8 mg/kg.

Slippage Test

K_c for beryllium is 3, and 9 site samples K_c exceed the maximum background measurement. Because $K > K_c$ beryllium fails the Slippage test.

WRS Test

The p-level < 0.001 indicates a significant difference between the site and background distributions.

Box Plot

The site minimum, interquartile range, and maximum are higher than the corresponding background values (Figure 1-2).

Conclusion

Because beryllium in surface soil failed statistical comparison to background, it is carried forward for Tier 3 geochemical evaluation.

Cobalt

Tier 1 Evaluation

Two site samples exceed the background screening value of 15.15 mg/kg.

Slippage Test

K_c for cobalt is 3, and no site samples exceed the maximum background measurement. Because $K < K_c$ cobalt passes the Slippage test.

WRS Test

The WRS test p-level of 0.0012 indicates a significant difference between the site and background distributions.

Box Plot

The site minimum and interquartile range are higher than that of background (Figure 1-2). The site maximum is lower than the corresponding background value.

Conclusion

Because cobalt in surface soil failed statistical comparison to background, it is carried forward for Tier 3 geochemical evaluation.

Copper

Tier 1 Evaluation

Seventeen site samples exceed the background screening value of 12.71 mg/kg.

Slippage Test

K_c for copper is 3, and six site samples exceed the maximum background measurement. Because $K > K_c$, copper fails the Slippage test.

WRS Test

The p-level < 0.001 indicates a significant difference between the site and background distributions.

Box Plot

The site minimum, interquartile range, and maximum are higher than the corresponding background values (Figure 1-3).

Conclusion

Because copper in surface soil failed statistical comparison to background, it is carried forward for Tier 3 geochemical evaluation.

Iron

Tier 1 Evaluation

Three site samples exceed the background screening value of 34,154 mg/kg.

Slippage Test

The critical value, K_c , for iron is 3. No site samples exceed the maximum background measurement. Because $K < K_c$ iron passes the Slippage test.

WRS Test

The p-level of 0.12 indicates weak agreement between the site and background distributions.

Box Plot

The site minimum is significantly higher than that of background. The 25th percentile and median are slightly elevated as compared to the corresponding background values (Figure 1-3). The site 75th percentile and maximum are slightly lower than that of background.

Conclusion

Because iron in surface soil failed statistical comparison to background, it is carried forward for Tier 3 geochemical evaluation.

Lead

Tier 1 Evaluation

Fourteen site samples exceed the background screening value of 40.05 mg/kg.

Slippage Test

K_c for lead is 3, and 4 site samples exceed the maximum background measurement. Because $K > K_c$, lead fails the Slippage test.

WRS Test

The p-level < 0.001 indicates a significance difference between the site and background distributions.

Box Plot

The box plot shows the site minimum, interquartile range, and maximum are higher than the corresponding background values (Figure 1-4).

Conclusion

Because lead in surface soil failed statistical comparison to background, it is carried forward for Tier 3 geochemical evaluation.

Magnesium

Tier 1 Evaluation

One site sample exceeds the background screening value of 1,033 mg/kg.

Slippage Test

K_c for magnesium is 3, and no site samples exceed the maximum background measurement. Because $K < K_c$, magnesium passes the Slippage test.

WRS Test

The p-level < 0.001 indicates a significant difference between the site and background distributions.

Box Plot

The site minimum and interquartile range are higher than the corresponding background values (Figure 1-4). The site maximum is lower than that of background.

Conclusion

Because magnesium in surface soil failed statistical comparison to background it will be carried forward for Tier 3 geochemical evaluation.

Manganese

Tier 1 Evaluation

Six site samples exceed the background screening value of 1,579 mg/kg.

Slippage Test

K_c for manganese is 3, and no site samples exceed the maximum background measurement. Because $K < K_c$, manganese passes the Slippage test.

WRS Test

The p-level < 0.001 indicates a significant difference between the site and background distributions.

Box Plot

The site minimum and interquartile range are higher than the corresponding background values (Figure 1-5). The site maximum is lower than that of background.

Conclusion

Because manganese in surface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Mercury

Tier 1 Evaluation

Five site samples exceed the background screening value of 0.08 mg/kg.

Slippage Test

K_c for mercury is 3, and no site samples exceed the maximum background measurement. Because $K < K_c$, mercury passes the Slippage test.

WRS Test

The WRS test was not performed because the background data set contains more than 50 percent nondetects.

Box Plot

The site minimum and interquartile range are higher than the corresponding background values (Figure 1-5). The shape and location of the background box plot is influenced by the high percentage of nondetects (66 percent), and the replacement values of one-half the reporting limit, rather than detected concentrations.

Hot Measurement Test

The site MDC exceeded the background 95th percentile of 0.125 mg/kg.

Conclusion

Because mercury in surface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Nickel

Tier 1 Evaluation

Six site samples exceed the background screening value of 10.33 mg/kg.

Slippage Test

K_c for nickel is 3, and no site samples exceed the maximum background measurement. Because $K < K_c$, nickel passes the Slippage test.

WRS Test

The p-level < 0.001 indicates a significant difference between the site and background distributions.

Box Plot

The site minimum and interquartile range are higher than the corresponding background values (Figure 1-6). The site maximum is lower than that of background.

Conclusion

Because nickel in surface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Potassium

Tier 1 Evaluation

Two site samples exceed the background screening value of 799.76 mg/kg.

Slippage Test

K_c for potassium is 3, and no site samples exceed the maximum background measurement. Because $K < K_c$, potassium passes the Slippage test.

WRS Test

The p-level < 0.001 indicates a significant difference between the site and background distributions.

Box Plot

The site minimum and interquartile range are higher than the corresponding background values (Figure 1-6). The site minimum is less than that of background.

Conclusion

Because potassium in surface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Selenium

Tier 1 Evaluation

One site sample exceeds the background screening value of 0.48 mg/kg.

Slippage Test

K_c for selenium is 3, and no site samples exceed the maximum background measurement. Because $K < K_c$, selenium passes the Slippage test.

WRS Test

No WRS test was performed because the site and background data sets contain more than 50 percent nondetects.

Box Plot

The site minimum and interquartile range are higher than the corresponding background values (Figure 1-7). The site maximum is lower than that of background. The shape and location of the background and site box plots are influenced by the high percentage of nondetects (99 percent and 95 percent respectively), and the replacement values of one-half the reporting limit, rather than detected concentrations.

Hot Measurement Test

The site MDC exceeds the background 95th percentile of 0.563 mg/kg.

Conclusion

Because selenium in surface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Silver

Tier 1 Evaluation

Two site samples exceed the background screening value of 0.36 mg/kg.

Slippage Test

K_c for silver is 3, and no site samples exceed the maximum background measurement. Because $K < K_c$, silver passes the Slippage test.

WRS Test

No WRS test was performed because the site data set contains more than 50 percent nondetects.

Box Plot

The site minimum and interquartile range are higher than the corresponding background values (Figure 1-7). The shape and location of the site box plot is influenced by the high percentage of nondetects (90 percent), and the replacement values of one-half the reporting limit, rather than detected concentrations.

Hot Measurement Test

The site MDC exceeds the background 95th percentile of 0.774 mg/kg.

Conclusion

Because silver in surface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Vanadium

Tier 1 Evaluation

One site sample exceeds the background screening value of 58.84 mg/kg.

Slippage Test

K_c for vanadium is 3, and no site samples exceed the maximum background measurement. Because $K < K_c$, vanadium passes the Slippage test.

WRS Test

The p-level of 0.099 indicates weak agreement between the site and background distributions.

Box Plot

The site minimum, 25th percentile, and median are higher than the corresponding background values (Figure 1-8). The site maximum and 75th percentile is lower than that of background.

Conclusion

Because vanadium in surface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Zinc

Tier 1 Evaluation

Three site samples exceed the background screening value of 40.64 mg/kg.

Slippage Test

K_c for zinc is 3, and no site samples exceed the maximum background measurement. Because $K < K_c$, zinc passes the Slippage test.

WRS Test

The p-level < 0.001 indicates a significant difference between the site and background distributions.

Box Plot

The site minimum and interquartile range are higher than the respective background values (Figure 1-8). The site maximum is lower than that of background.

Conclusion

Because zinc in surface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

3.2 Subsurface Soil

Twenty-three TAL metals were evaluated in subsurface soil samples from Parcels 100Q and 101Q. Antimony, cadmium, and thallium had no detected concentrations in subsurface soil site samples, so no further discussion of these metals is included.

Five metals, calcium, chromium, copper, sodium, and vanadium had no detected concentrations above the background screening value, passing the Tier 1 evaluation. No further discussion of these metals is included.

The remaining 15 elements were carried forward for Tier 2 evaluation. The statistical tests and box plots are discussed in detail below.

Table 2 summarizes the Tier 1 and Tier 2 test results for subsurface soil.

Aluminum

Tier 1 Evaluation

Thirteen site samples exceed the background screening value of 13,591 mg/kg.

Slippage Test

The critical value, K_c , for aluminum is 3. Two site samples exceed the maximum background measurement. Because $K < K_c$ aluminum passes the Slippage test.

WRS Test

The WRS test p-level < 0.001 indicates a significant difference between the site and background distributions.

Box Plot

Box plots for the site and background data sets are provided in Figure 1-9. The site minimum, interquartile range, and maximum are higher than the corresponding background values.

Conclusion

Because aluminum in subsurface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Arsenic

Tier 1 Evaluation

One site sample exceeds the background screening value of 18.3 mg/kg.

Slippage Test

K_c for arsenic is 3, and no site samples exceed the maximum background measurement. Because $K < K_c$, arsenic passes the Slippage test.

WRS Test

The p-level of 0.37 indicates good agreement between the site and background distributions.

Box Plot

The site median is similar to that of background. The site minimum and 25th percentile are higher than the corresponding background values (Figure 1-9). The site 75th percentile and maximum are lower than the corresponding background values.

Conclusion

Arsenic in subsurface soil is considered to be within the range of background.

Barium

Tier 1 Evaluation

One site sample exceeds the background screening value of 233.62 mg/kg.

Slippage Test

K_c for barium is 3, and no site samples exceed the maximum background measurement. Because $K < K_c$, barium passes the Slippage test.

WRS Test

The p-level of 0.0017 indicates a significant difference between the site and background distributions.

Box Plot

The site minimum and interquartile range are higher than the corresponding background values (Figure 1-10). The site maximum is lower than that of background.

Conclusion

Because barium in subsurface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Beryllium

Tier 1 Evaluation

Four site samples exceed the background screening value of 0.86 mg/kg.

Slippage Test

K_c for beryllium is 3, and one site sample exceeds the maximum background measurement. Because $K < K_c$, beryllium passes the Slippage test.

WRS Test

The p-level < 0.001 indicates a significant difference between the site and background distributions.

Box Plot

The site minimum and interquartile range are higher than the corresponding background values (Figure 1-10). The site and background maximums are similar.

Conclusion

Because beryllium in subsurface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Cobalt

Tier 1 Evaluation

Four site samples exceed the background screening value of 17.54 mg/kg.

Slippage Test

K_c for cobalt is 3, and one site sample exceeds the maximum background measurement. Because $K < K_c$, cobalt passes the Slippage test.

WRS Test

The p-level of 0.0012 indicates a significant difference between the site and background distributions.

Box Plot

The site minimum and interquartile range are higher than the corresponding background values (Figure 1-11).

Conclusion

Because cobalt in subsurface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Iron

Tier 1 Evaluation

Three site samples exceed the background screening value of 44,817 mg/kg.

Slippage Test

K_c for iron is 3, and one site sample exceeds the maximum background measurement. Because $K < K_c$, iron passes the Slippage test.

WRS Test

The p-level of 0.419 indicates good agreement between the site and background distributions.

Box Plot

The site minimum and 25th percentile are higher than the corresponding background values. The site median and 75th percentile are similar to that of background, and the site maximum is higher than that of background (Figure 1-11).

Conclusion

Iron in subsurface soil is considered to be within the range of background.

Lead

Tier 1 Evaluation

Four site samples exceed the background screening value of 38.53 mg/kg.

Slippage Test

K_c for lead is 3, and no site sample exceeds the maximum background measurement. Because $K < K_c$, lead passes the Slippage test.

WRS Test

The p-level < 0.001 indicates a significant difference between the site and background distributions.

Box Plot

The site minimum and interquartile range are higher than the corresponding background values. The site maximum is lower than that of background (Figure 1-12).

Conclusion

Because lead in subsurface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Magnesium

Tier 1 Evaluation

Four site samples exceed the background screening value of 766.24 mg/kg.

Slippage Test

K_c for magnesium is 3, and no site samples exceed the maximum background measurement. Because $K < K_c$, magnesium passes the Slippage test.

WRS Test

The p-level of < 0.001 indicates a significant difference between the site and background distributions.

Box Plot

The site minimum and interquartile range are higher than the corresponding background values (Figure 1-12). The site maximum is lower than that of background.

Conclusion

Because magnesium in subsurface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Manganese

Tier 1 Evaluation

Five site samples exceed the background screening value of 1,355 mg/kg.

Slippage Test

K_c for manganese is 3, and no site samples exceed the maximum background measurement. Because $K < K_c$, manganese passes the Slippage test.

WRS Test

The p-level of 0.0017 indicates a significant difference between the site and background distributions.

Box Plot

The site minimum and interquartile range are higher than the corresponding background values (Figure 1-13). The site maximum is lower than that of background.

Conclusion

Because manganese in subsurface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Mercury

Tier 1 Evaluation

Ten site samples exceed the background screening value of 0.07 mg/kg.

Slippage Test

K_c for mercury is 3, and 2 site samples exceed the maximum background measurement. Because $K < K_c$, mercury passes the Slippage test.

WRS Test

No WRS test was performed because the background data set contains more than 50 percent nondetects.

Box Plot

The site minimum, interquartile range, and maximum appear significantly higher than the corresponding background values (Figure 1-13). The shape and location of the background box plot is influenced by the nondetects (53 percent), and the replacement values of one-half the reporting limit, rather than detected concentrations.

Hot Measurement Test

The maximum detected concentration of mercury exceeds the background 95th percentile of 0.094 mg/kg.

Conclusion

Because mercury in subsurface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Nickel

Tier 1 Evaluation

Five site samples exceed the background screening value of 12.89 mg/kg.

Slippage Test

K_c for nickel is 3, and no site samples exceed the maximum background measurement. Because $K < K_c$, nickel passes the Slippage test.

WRS Test

The p-level of 0.0026 indicates a significant difference between the site and background distributions.

Box Plot

The site minimum and interquartile range are higher than the corresponding background values (Figure 1-14). The site maximum is lower than that of background.

Conclusion

Because nickel in subsurface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Potassium

Tier 1 Evaluation

Three site samples exceed the background screening value of 710.74 mg/kg.

Slippage Test

K_c for potassium is 3 and no site samples exceed the maximum background measurement. Because $K < K_c$, potassium passes the Slippage test.

WRS Test

The p-level < 0.001 indicates a significant difference between site and background distributions.

Box Plot

The site minimum and interquartile range are higher than the corresponding background values (Figure 1-14), and the site maximum is significantly lower than that of background.

Conclusion

Because potassium in subsurface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Selenium

Tier 1 Evaluation

Six site samples exceed the background screening value of 0.47 mg/kg.

Slippage Test

The Slippage test is not performed because the maximum value for background is a nondetect.

WRS Test

No WRS test was performed because the site and background data sets contain more than 50 percent nondetects.

Box Plot

The site minimum, interquartile range, and maximum are higher than the corresponding background values (Figure 1-15). The shape and location of the background and site box plots are influenced by the high percentage of nondetects (98 percent and 71 percent, respectively), and the replacement values of one-half the reporting limit, rather than detected concentrations.

Hot Measurement Test

The site MDC exceeds the background 95th percentile of 0.574 mg/kg.

Conclusion

Because selenium in subsurface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Silver

Tier 1 Evaluation

Six site samples exceed the background screening value of 0.24 mg/kg.

Slippage Test

The Slippage test is not performed because the maximum value for background is a nondetect.

WRS Test

No WRS test was performed because the site data set contains more than 50 percent nondetects.

Box Plot

The site minimum, interquartile range, and maximum are higher than the corresponding background values (Figure 1-15). The shape and location of the site box plot is influenced by the high percentage of nondetects (71 percent), and the replacement values of one-half the reporting limit, rather than detected concentrations.

Hot Measurement Test

The site MDC exceeds the background 95th percentile of 0.88 mg/kg.

Conclusion

Because silver in subsurface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Zinc

Tier 1 Evaluation

Eight site samples exceed the background screening value of 34.86 mg/kg.

Slippage Test

K_c for zinc is 3, and no site samples exceed the maximum background measurement. Because $K < K_c$, zinc passes the Slippage test.

WRS Test

The p-level < 0.001 indicates a significant difference between site and background distributions.

Box Plot

The site minimum and interquartile range are higher than the corresponding background values (Figure 1-16). The site maximum is lower than that of background.

Conclusion

Because zinc in subsurface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

3.3 Groundwater

This section presents the results of the site-to-background comparisons for 23 TAL metals in unfiltered groundwater samples from Parcels 100Q and 101Q.

Thirteen metals, (antimony, Arsenic, beryllium, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver, thallium, vanadium, and zinc), had no detected concentrations in the site samples and are not considered any further.

The remaining ten metals (aluminum, barium, calcium, cobalt, iron, magnesium, manganese, potassium, sodium, and zinc) had no detected concentrations above the background screening value, passing the Tier 1 evaluation. These metals will not be tested or discussed any further.

The results of the groundwater evaluation are summarized in Table 3.

3.4 Sediment

This section presents the results of the site-to-background comparisons for 23 TAL metals for Parcels 100Q and 101Q sediment samples. Five metals, (antimony, cadmium, selenium, silver,

and thallium) had no detected concentrations in sediment. No further discussion of these elements is included.

Eleven metals, (arsenic, calcium, chromium, cobalt, iron, magnesium, mercury, potassium, sodium, vanadium, and zinc) had no detected results that exceeded the background screening value. These metals are considered to be within the range of background based on the Tier 1 evaluation. They will not be tested or discussed any further.

Seven metals underwent Tier 2 evaluation and are discussed in detail below.

Table 4 summarizes the Tier 1 and Tier 2 results for sediment.

Aluminum

Tier 1 Evaluation

Three site samples exceed the background screening value of 8,593 mg/kg.

Slippage Test

K_c for aluminum is 1, and one site sample exceeds the maximum background measurement. Because $K \leq K_c$, aluminum passes the Slippage test.

WRS Test

The WRS test is not performed on sample sizes less than 5.

Box Plot

The site minimum and interquartile box are significantly higher than the corresponding background values (Figure 1-17). The site and background maximums appear to be the same.

Hot Measurement Test

The site MDC exceeds the background 95th UTL of 14,331 mg/kg.

Conclusion

Because aluminum in sediment failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Barium

Tier 1 Evaluation

Two site samples exceed the background screening value of 98.91 mg/kg.

Slippage Test

K_c for barium is 1, and no site sample exceeds the maximum background measurement. Because $K < K_c$, barium passes the Slippage test.

WRS Test

The WRS test is not performed on sample sizes less than 5.

Box Plot

The site minimum and interquartile box are higher than the corresponding background values (Figure 1-17). The site maximum is lower than that of background.

Hot Measurement Test

The site MDC is less than the background 95th UTL of 190.6 mg/kg.

Conclusion

Barium in sediment is considered to be within the range of background.

Beryllium

Tier 1 Evaluation

Three site samples exceed the background screening value of 0.97 mg/kg.

Slippage Test

K_c for beryllium is 2, and 2 site samples exceed the maximum background measurement. Because $K \leq K_c$, beryllium passes the Slippage test.

WRS Test

The WRS test is not performed on sample sizes less than 5.

Box Plot

The site minimum, interquartile box, and maximum are higher than the corresponding background values (Figure 1-18).

Hot Measurement Test

The site MDC exceeds the background 95th UTL of 1.826 mg/kg.

Conclusion

Because beryllium in sediment failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Copper

Tier 1 Evaluation

Three site samples exceed the background screening value of 17.12 mg/kg.

Slippage Test

K_c for copper is 2, and no site samples exceed the maximum background measurement. Because $K < K_c$, copper passes the Slippage test.

WRS Test

The WRS test is not performed on sample sizes less than 5.

Box Plot

The site minimum and interquartile box are higher than the corresponding background values (Figure 1-18). The site maximum is slightly lower than that of background.

Hot Measurement Test

The site MDC exceeds the background 95th UTL of 36.79 mg/kg.

Conclusion

Because copper in sediment failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Lead

Tier 1 Evaluation

Three site samples exceed the background screening value of 37.82 mg/kg.

Slippage Test

K_c for lead is 2, and 2 site samples exceed the maximum background measurement. Because $K \leq K_c$, lead passes the Slippage test.

WRS Test

The WRS test is not performed when the sample size is less than 5.

Box Plot

The site minimum, interquartile range, and maximum are higher than the corresponding background values (Figure 1-19).

Hot Measurement Test

The site MDC exceeds the background 95th UTL of 76.4 mg/kg.

Conclusion

Because lead in sediment failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Manganese

Tier 1 Evaluation

One site sample exceeds the background screening value of 712.31 mg/kg.

Slippage Test

K_c for manganese is 1, and no site samples exceed the maximum background measurement. Because $K < K_c$, manganese passes the Slippage test.

WRS Test

The WRS test is not performed when the sample size is less than 5.

Box Plot

The site minimum and interquartile range are higher than the corresponding background values (Figure 1-19). The site maximum is less than that of background.

Hot Measurement Test

The site MDC is less than the background 95th UTL of 2,611 mg/kg.

Conclusion

Manganese in sediment is considered to be within the range of background.

Nickel

Tier 1 Evaluation

One site sample exceeds the background screening value of 13.02 mg/kg.

Slippage Test

K_c for nickel is 1, and no site samples exceed the maximum background measurement. Because $K < K_c$, nickel passes the Slippage test.

WRS Test

The WRS test is not performed when the sample size is less than 5.

Box Plot

The site minimum and interquartile range are higher than the corresponding background values (Figure 1-20). The site maximum is lower than that of background.

Hot Measurement Test

The site MDC is less than the background 95th percentile of 25.8 mg/kg.

Conclusion

Nickel in sediment is considered to be within the range of background.

3.5 Surface Water

This section presents the results of the site-to-background comparisons for the 23 TAL metals for Parcels 100Q and 101Q surface water samples. Fourteen metals, (antimony, arsenic, beryllium, cadmium, chromium, cobalt, mercury, nickel, potassium, selenium, silver, thallium, vanadium, and zinc) had no detected concentrations in the site samples and are not evaluated or discussed further.

The remaining nine metals, (aluminum, barium, calcium, copper, iron, lead, magnesium, manganese, and sodium), had no detected concentrations exceeding their respective background screening values. These metals are considered within the range of background based on the Tier 1 evaluation. They will not be tested or discussed further.

Table 5 summarizes the results for surface water.

4.0 Summary and Conclusions

The statistical methodology used to compare site data from the Former Rifle/Machine Gun Ranges (Firing Line Areas), Parcels 100Q and 101Q, and background data, for 23 elements in surface soil, subsurface soil, groundwater, sediment, and surface water, includes a comparison of the site MDC to the background screening value (Tier 1 evaluation). Analytes that failed this comparison were subjected to the Slippage test, Wilcoxon rank sum test, and Hot Measurement test when applicable. A box-and-whisker plot was prepared to visually compare the two data sets and properly interpret the WRS test results. If the Slippage test and/or the WRS test could not be performed, the Hot Measurement test was done as part of the Tier 2 statistical evaluation. Analytes that underwent Tier 2 evaluation and failed any component of the statistical site-to-background comparison are carried forward for Tier 3 geochemical evaluation to determine if natural processes can explain the elevated concentrations.

Tables 1 through 5 summarize the comparison test results and the metals carried forward for geochemical evaluation.

5.0 References

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ATTACHMENT 1

Figure 1-1

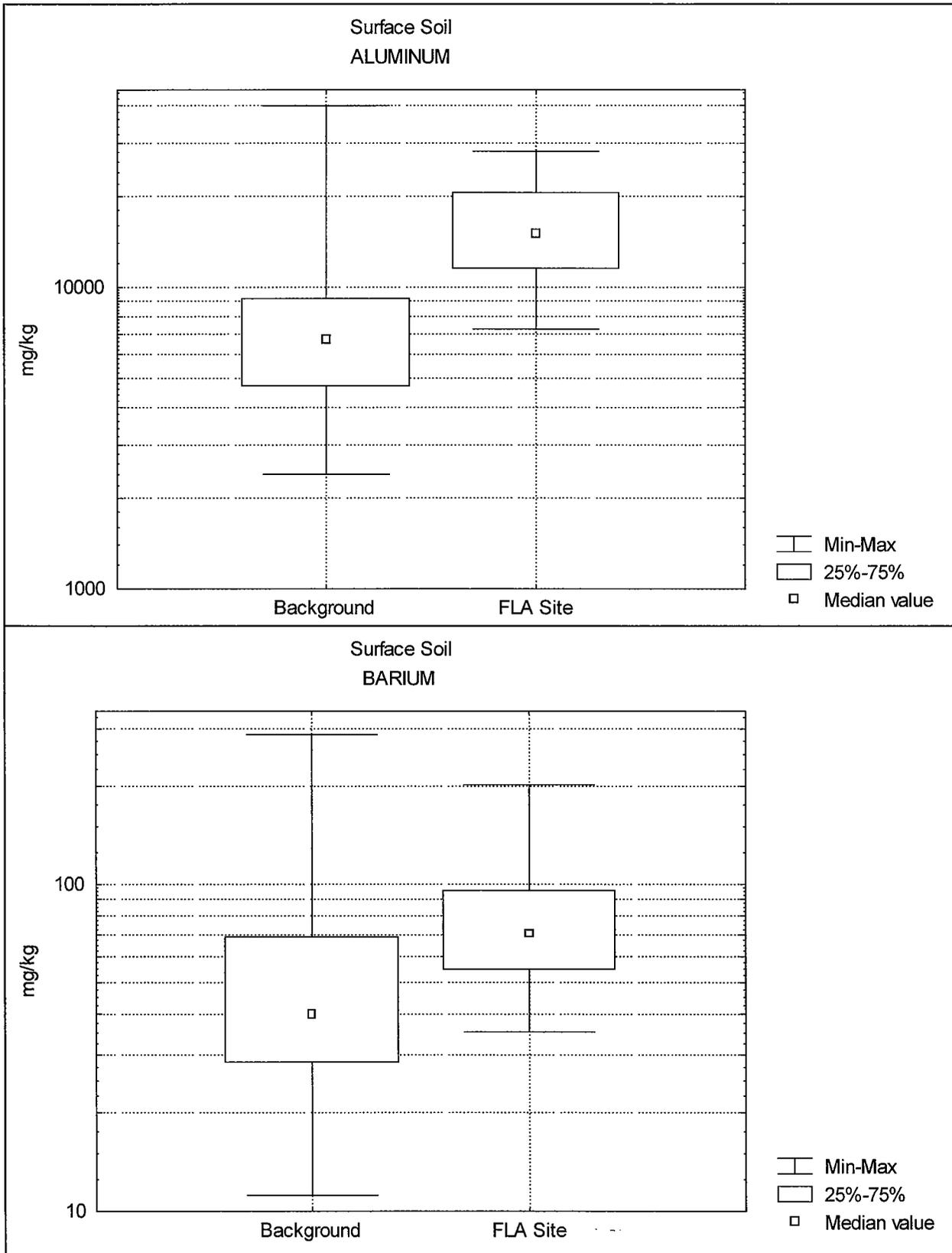


Figure 1-2

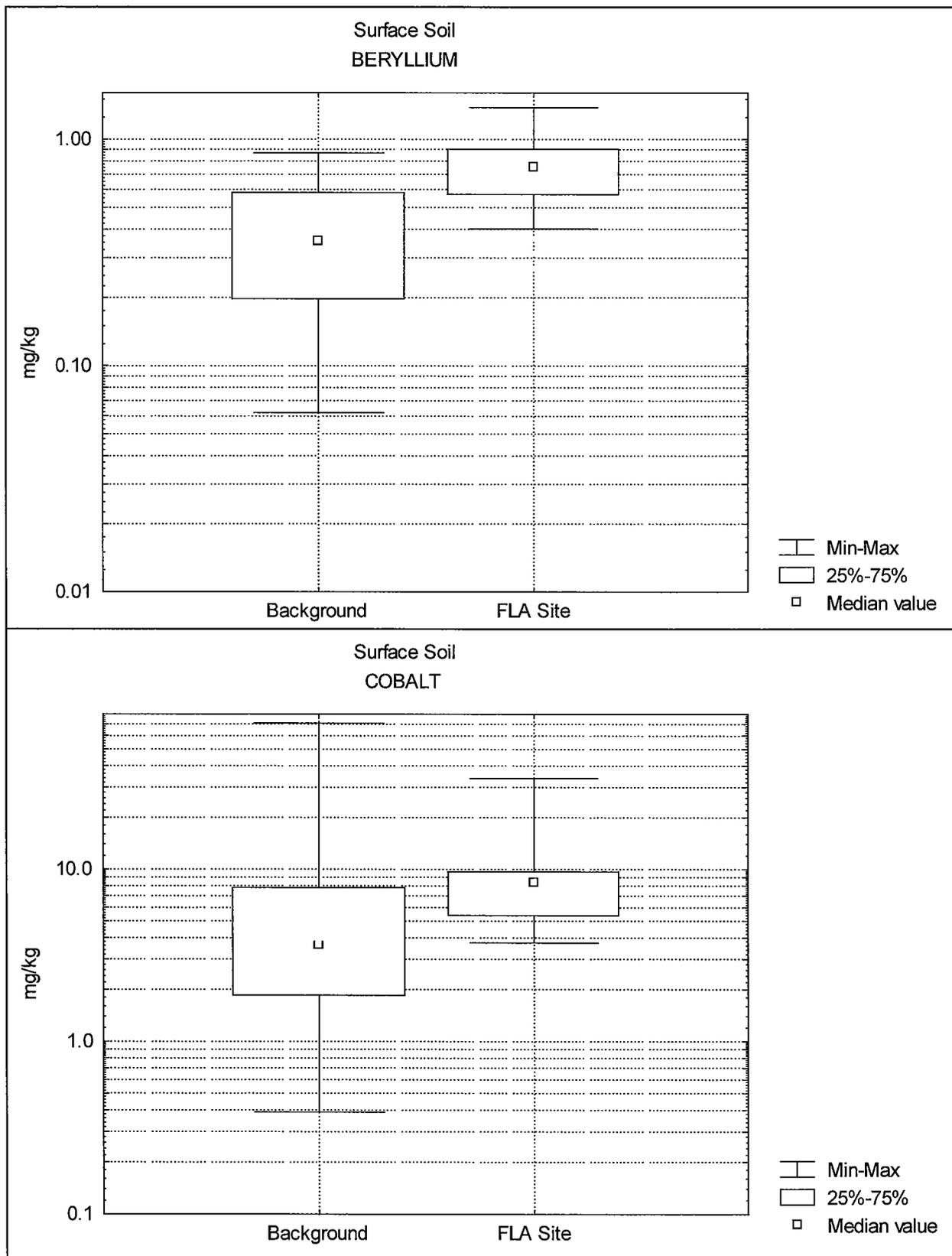


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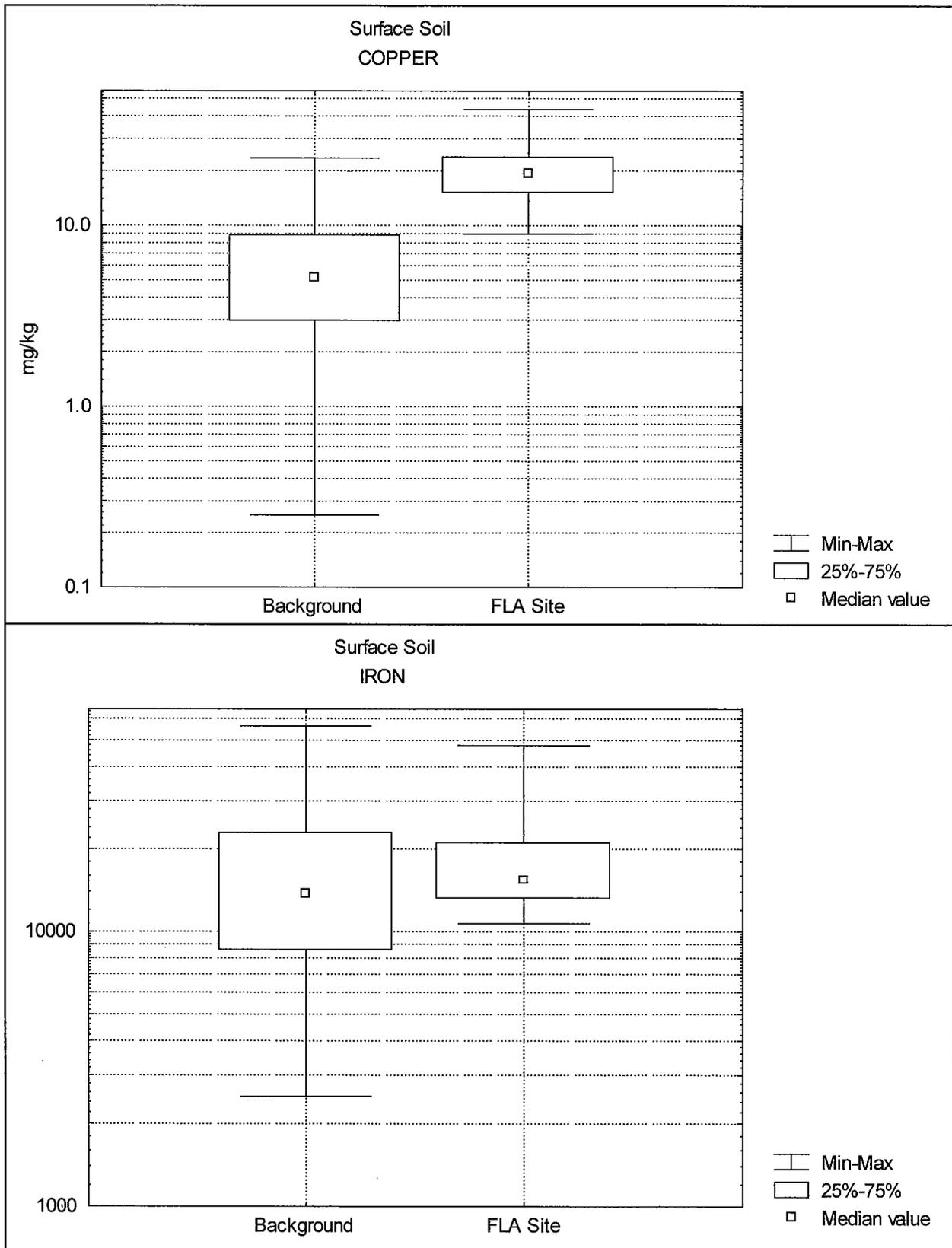


Figure 1-4

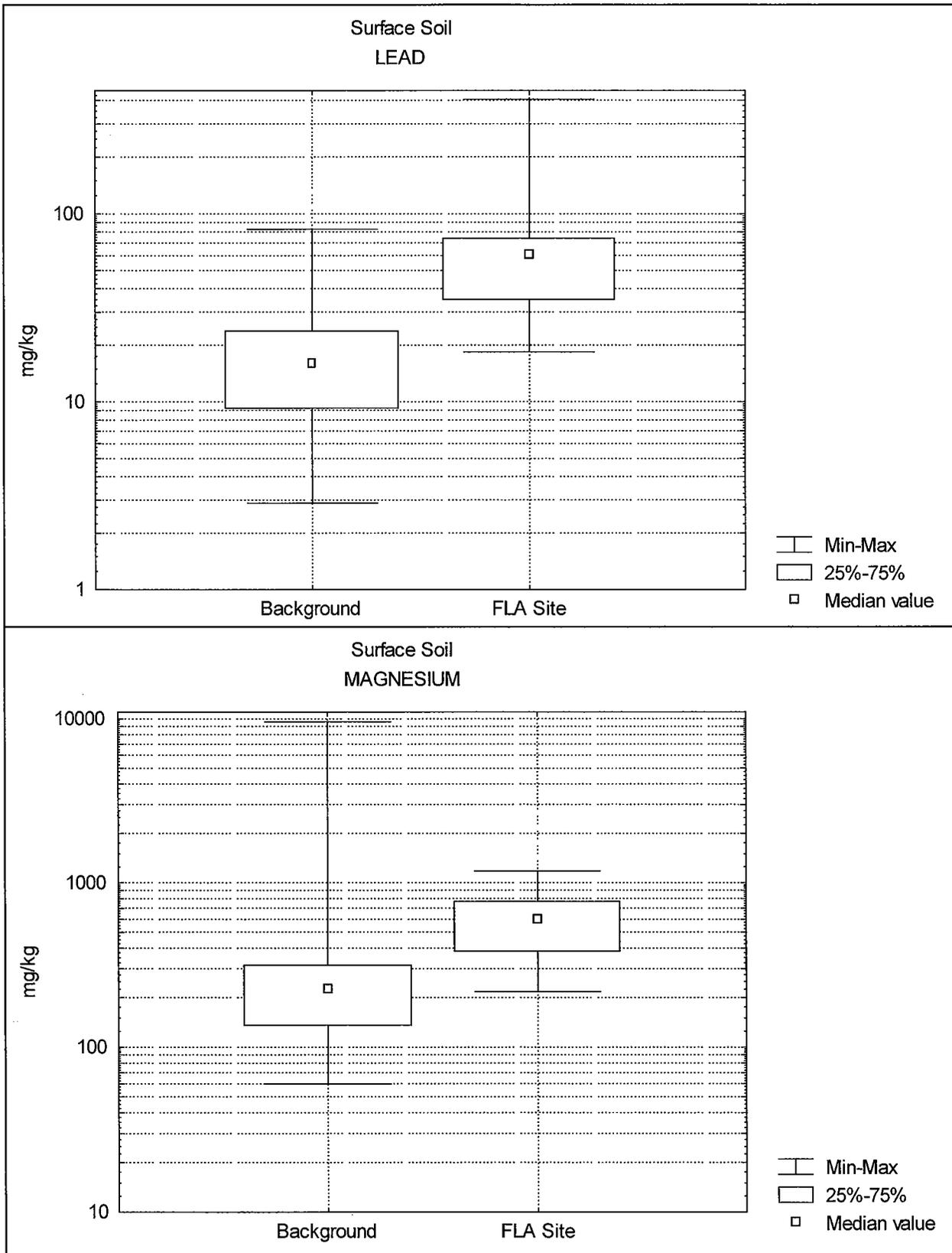


Figure 1-5

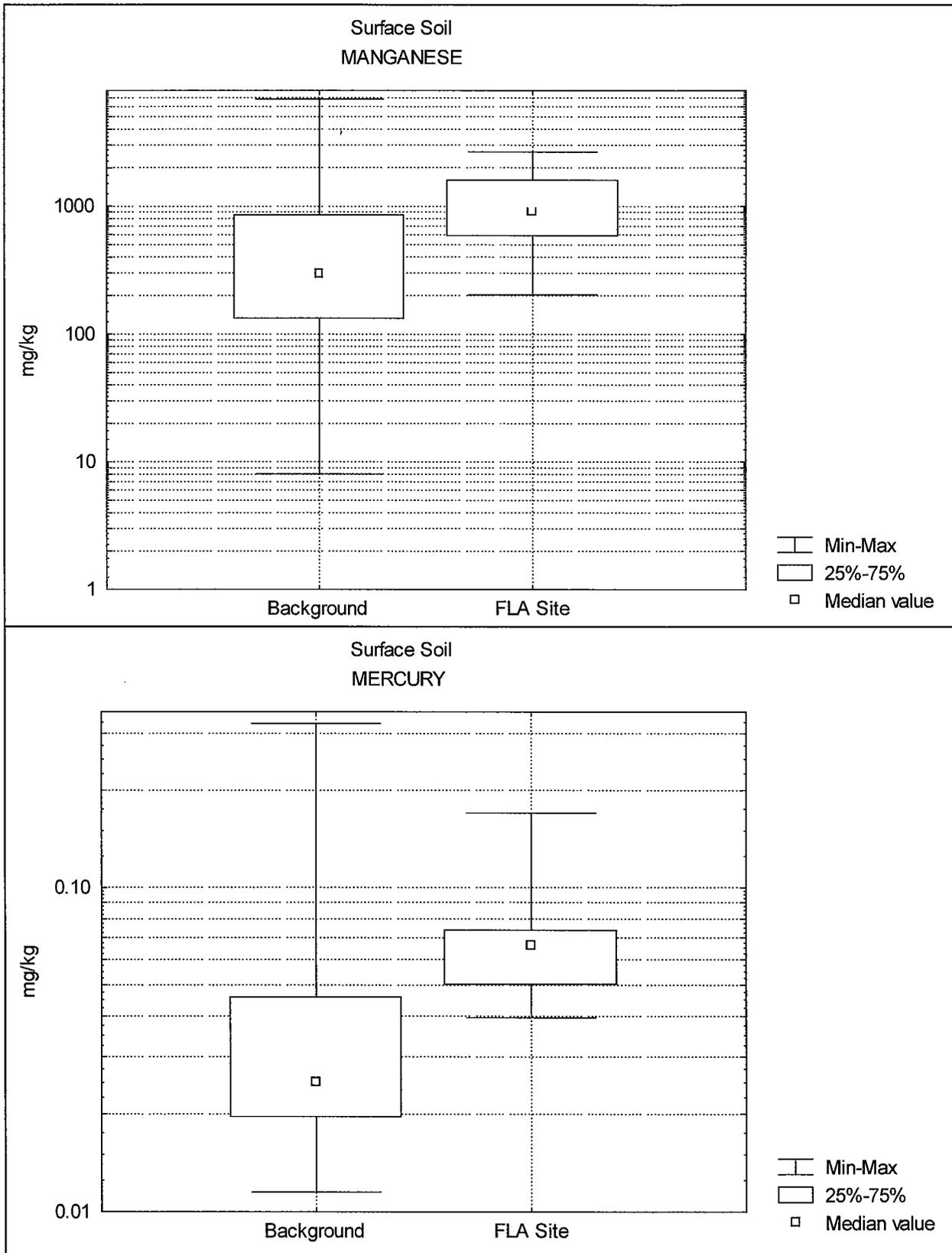


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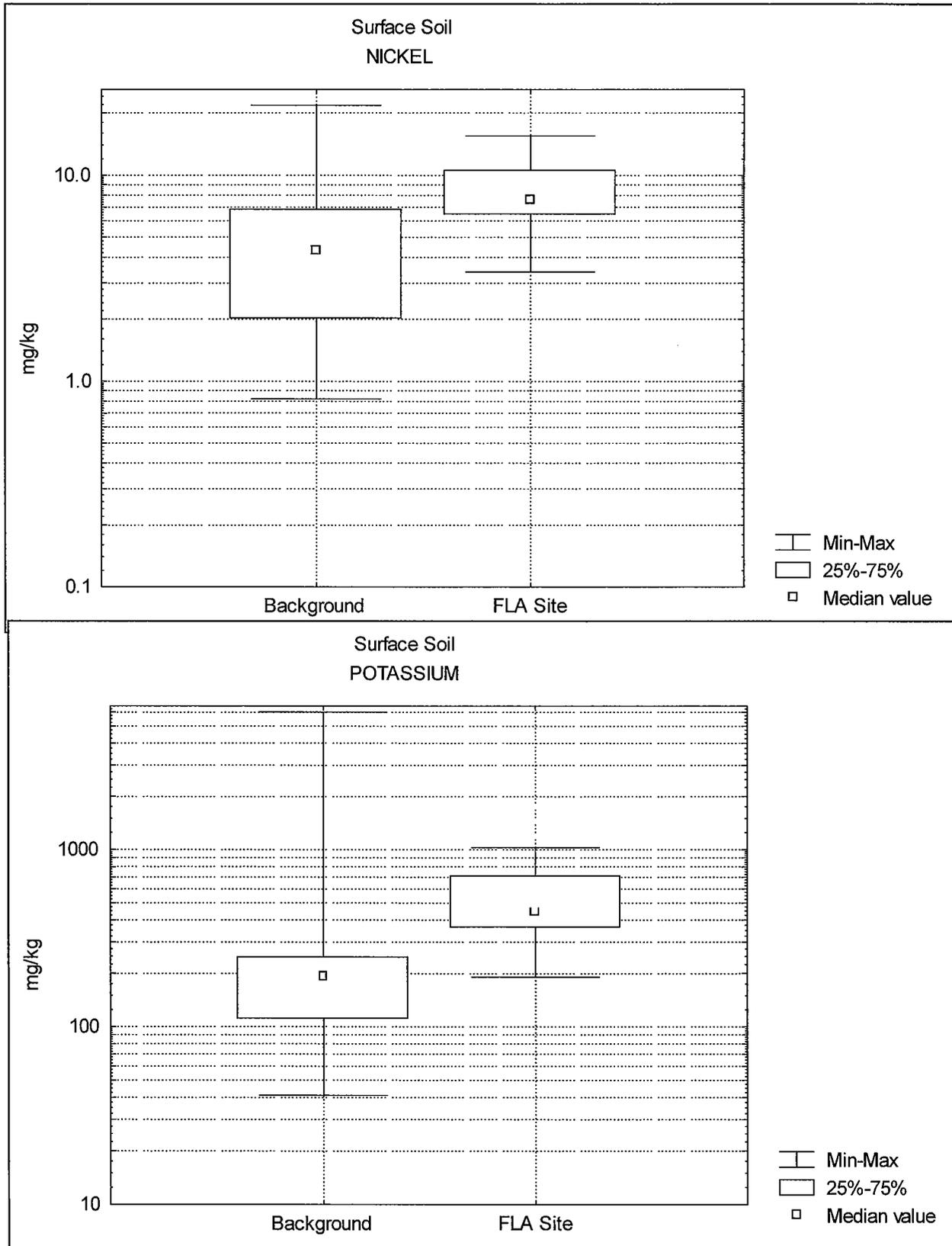


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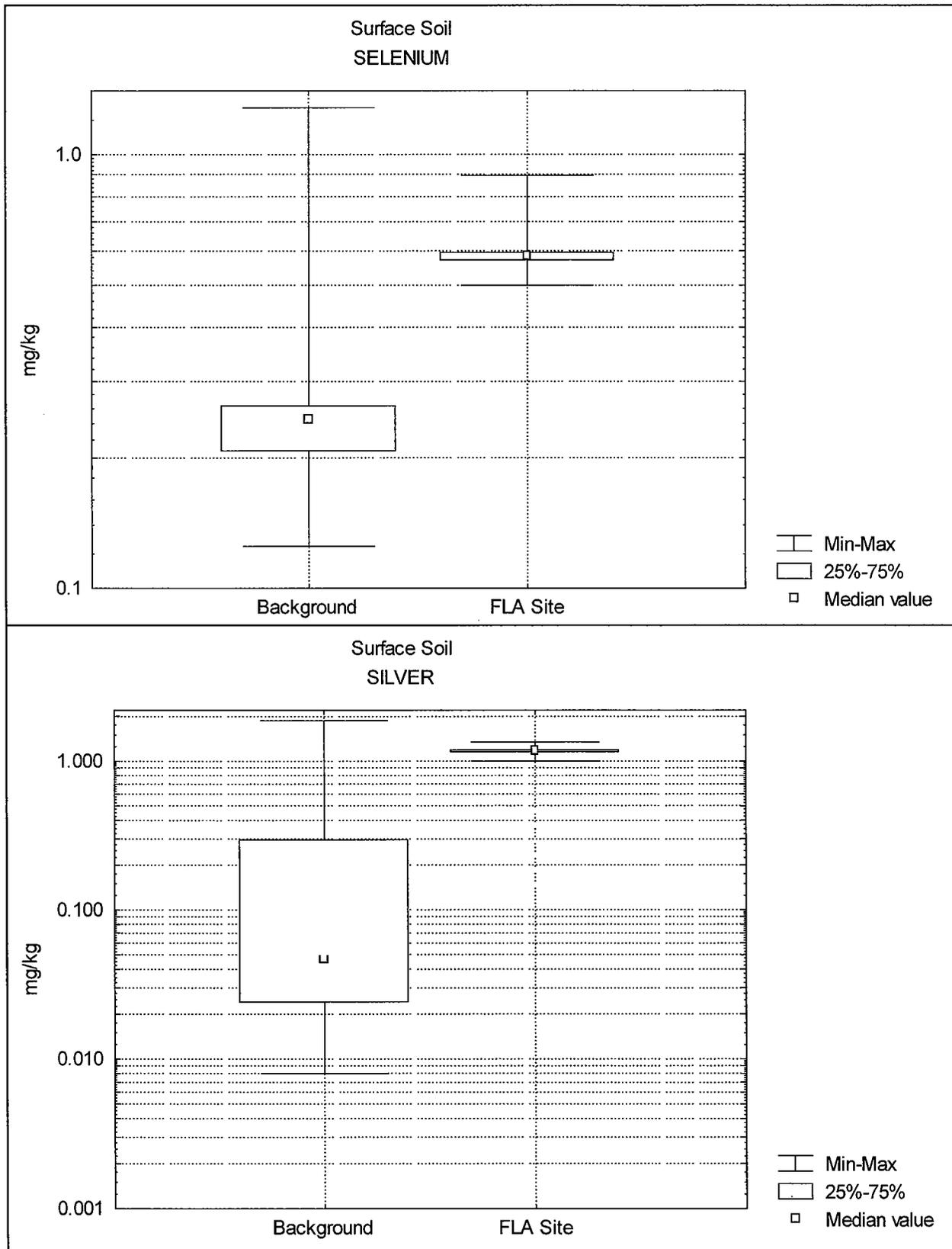


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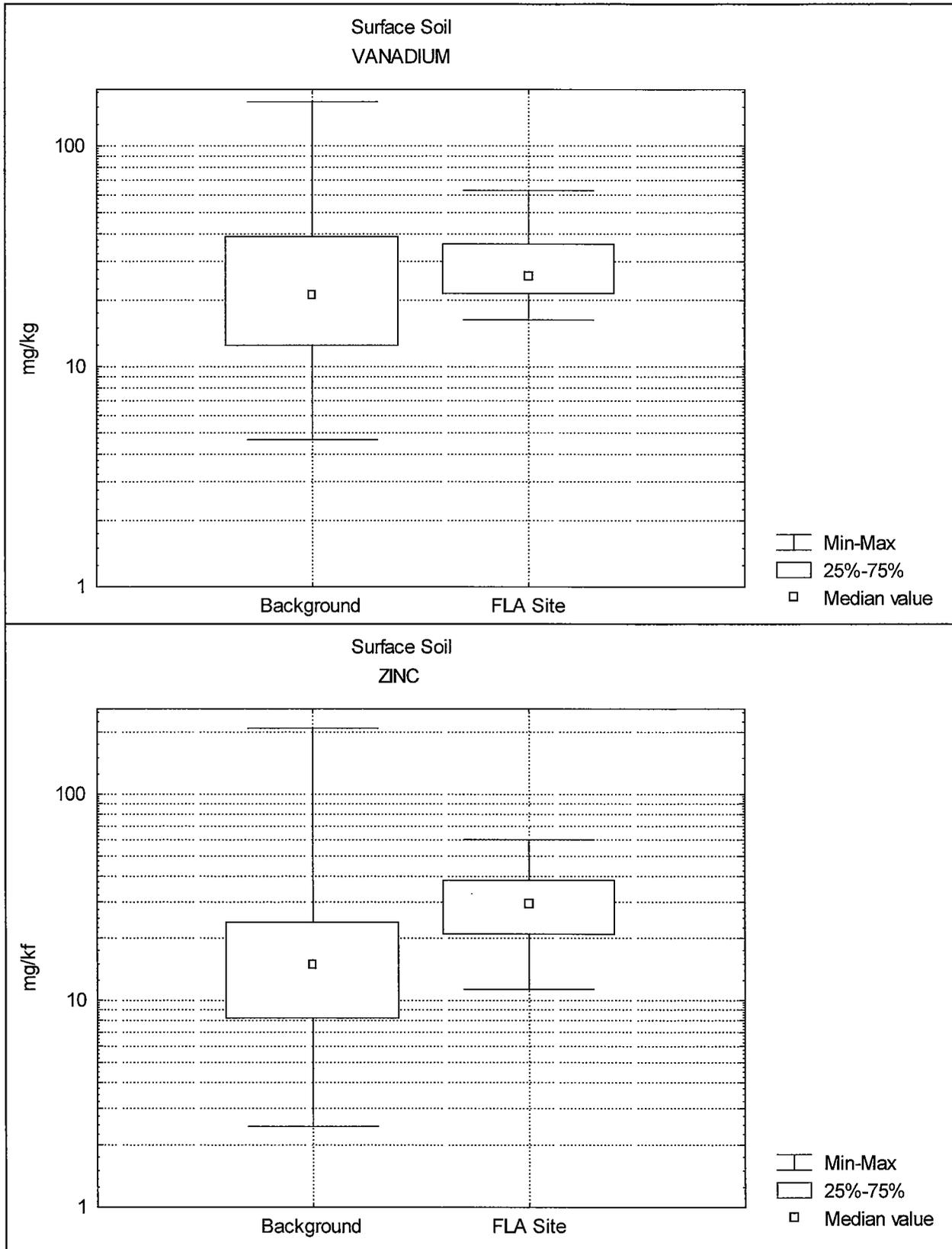


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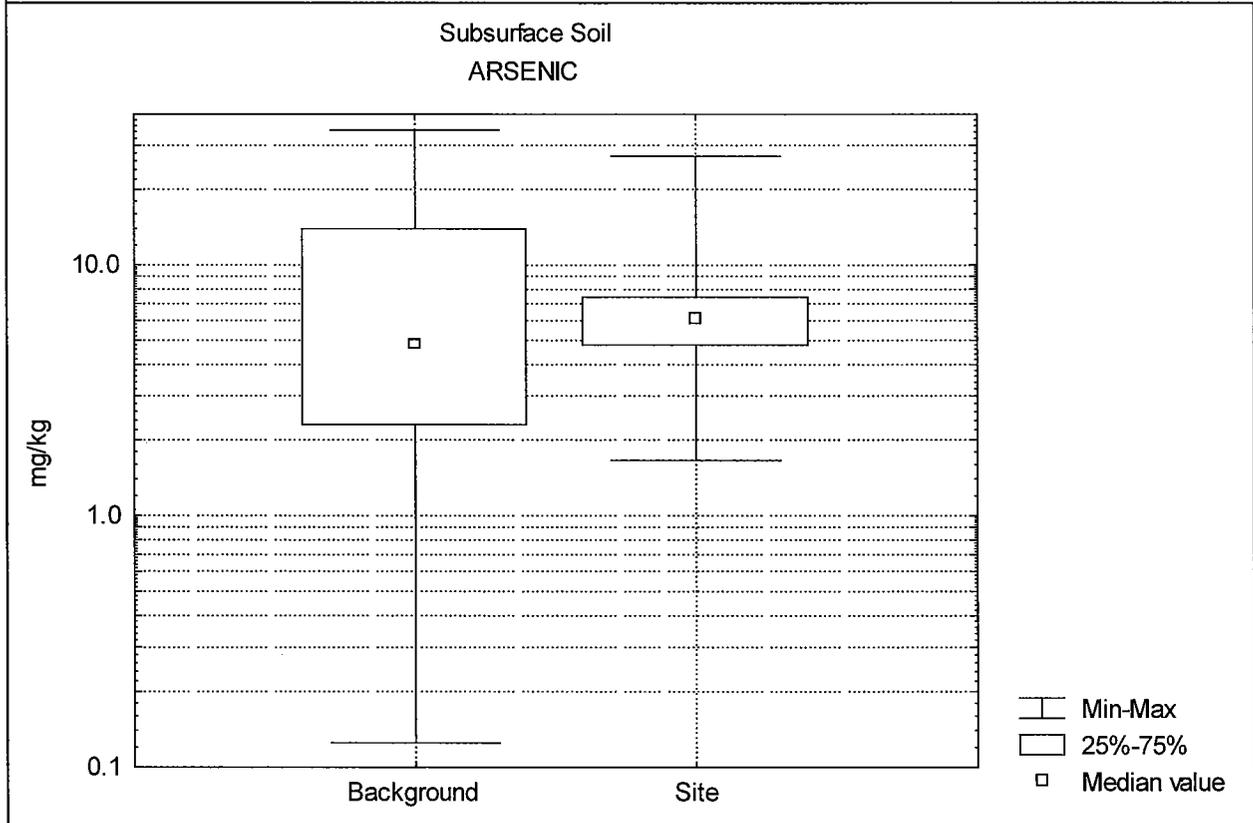
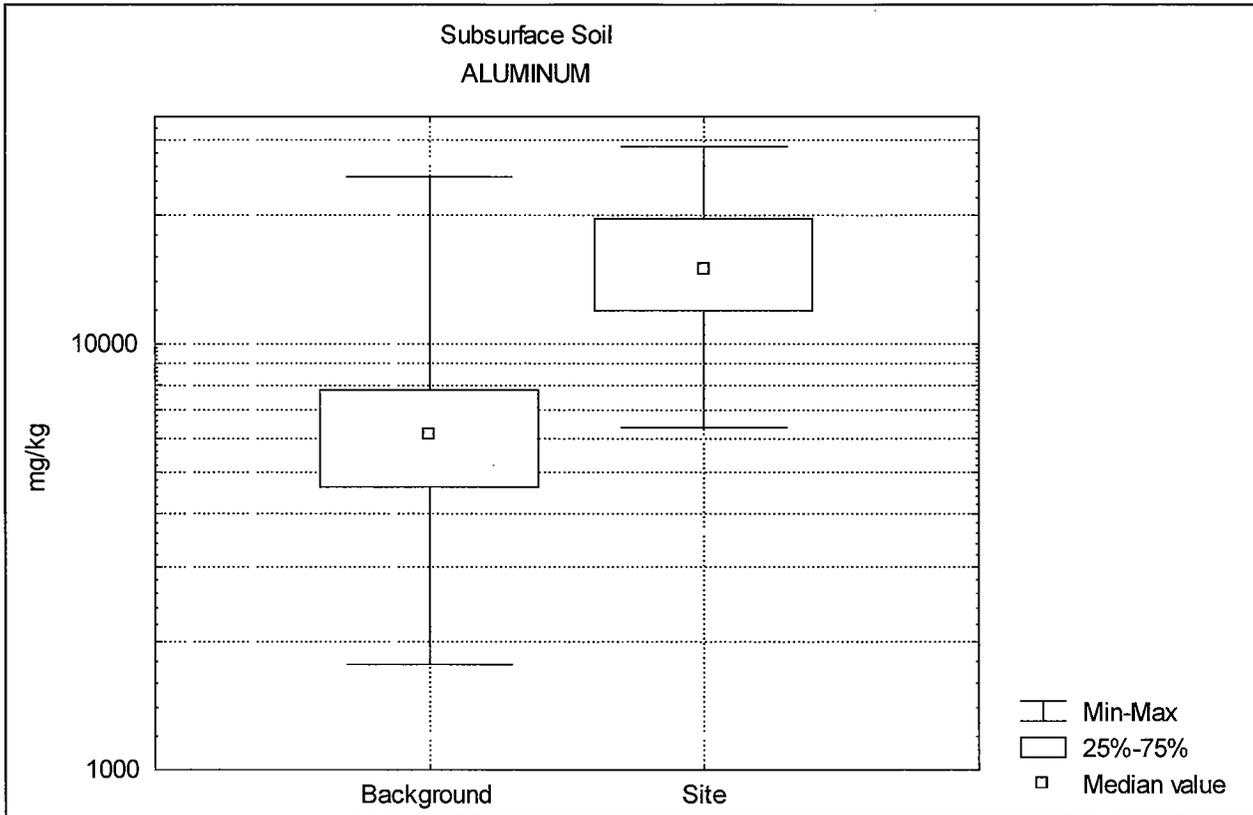


Figure 1-10

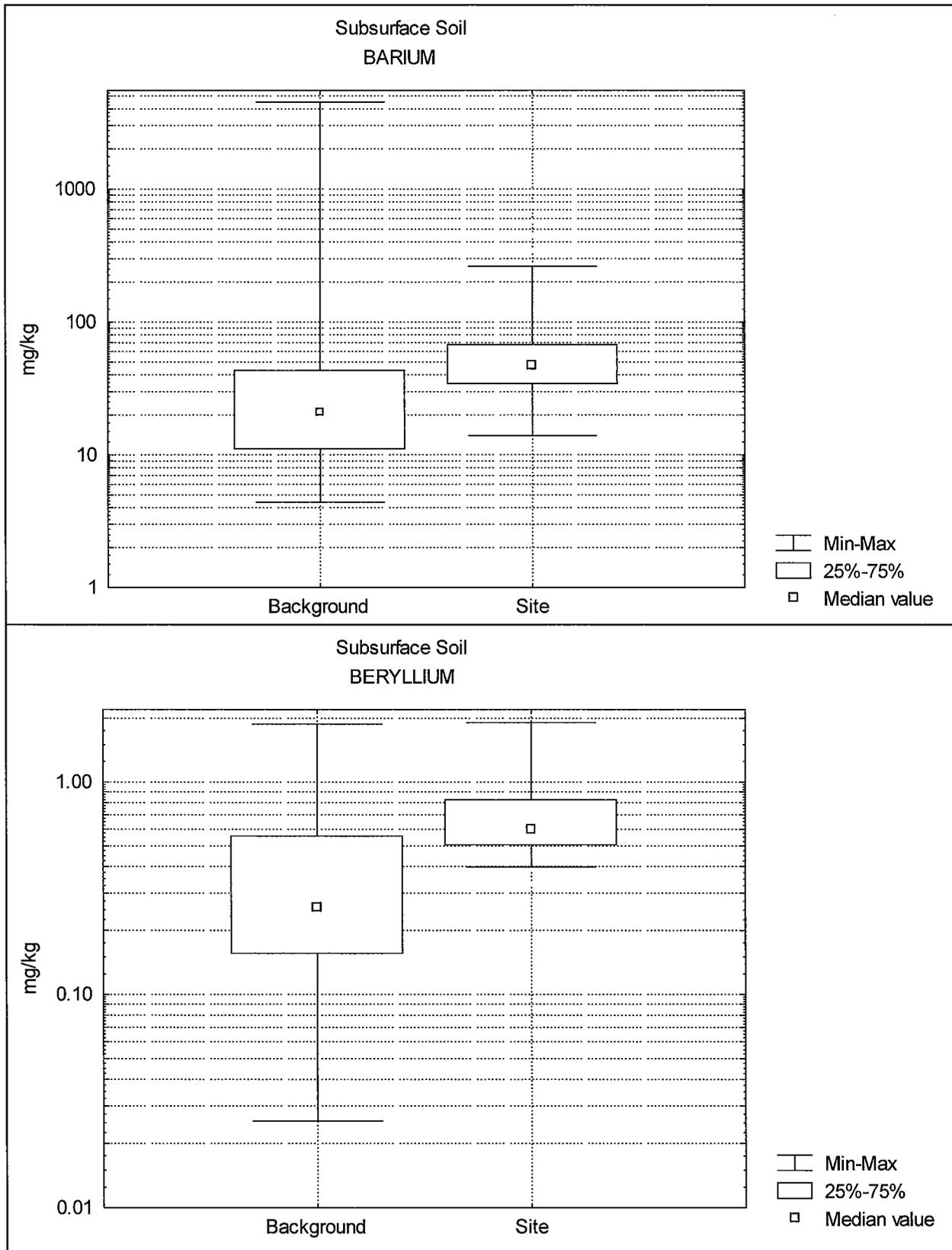


Figure 1-11

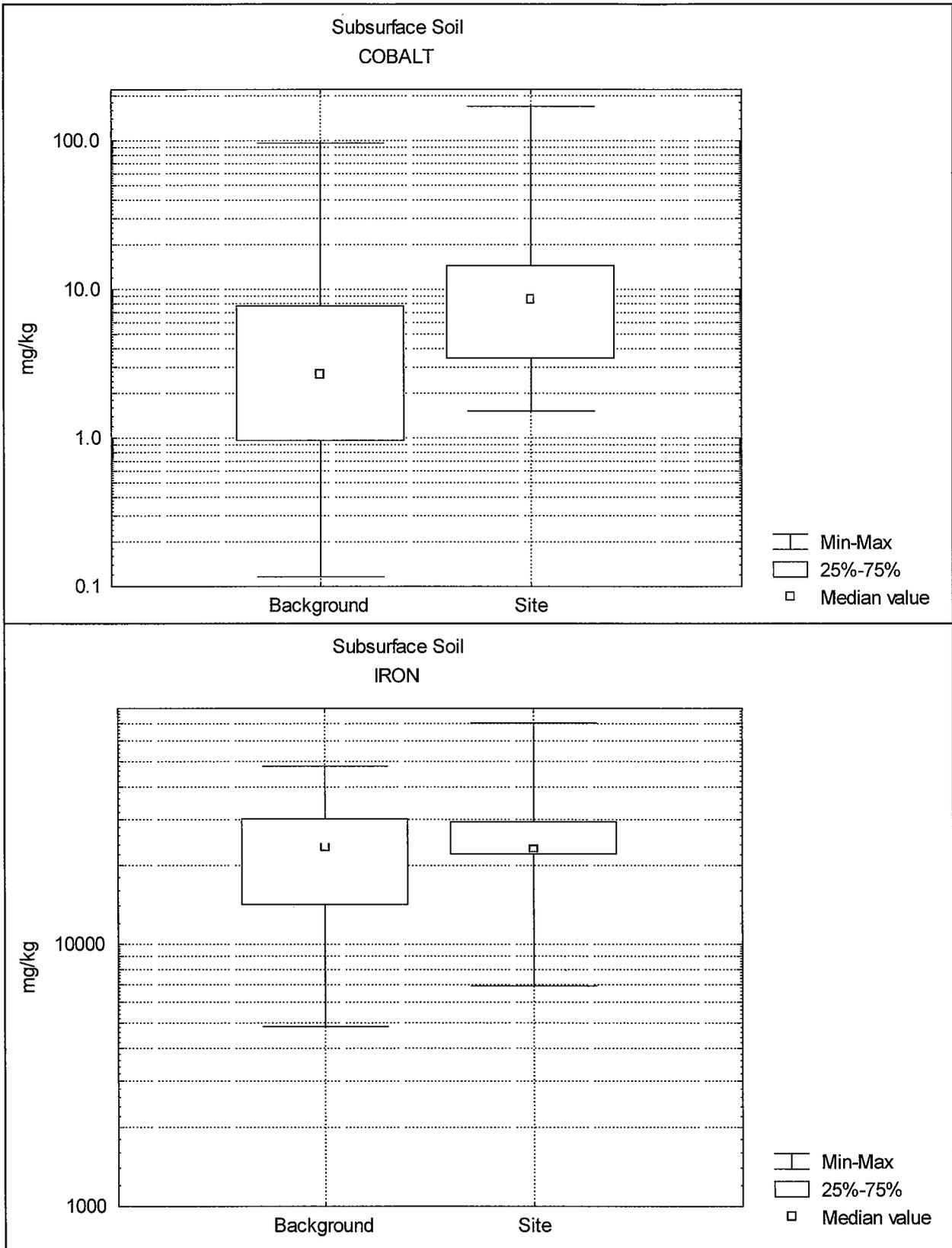


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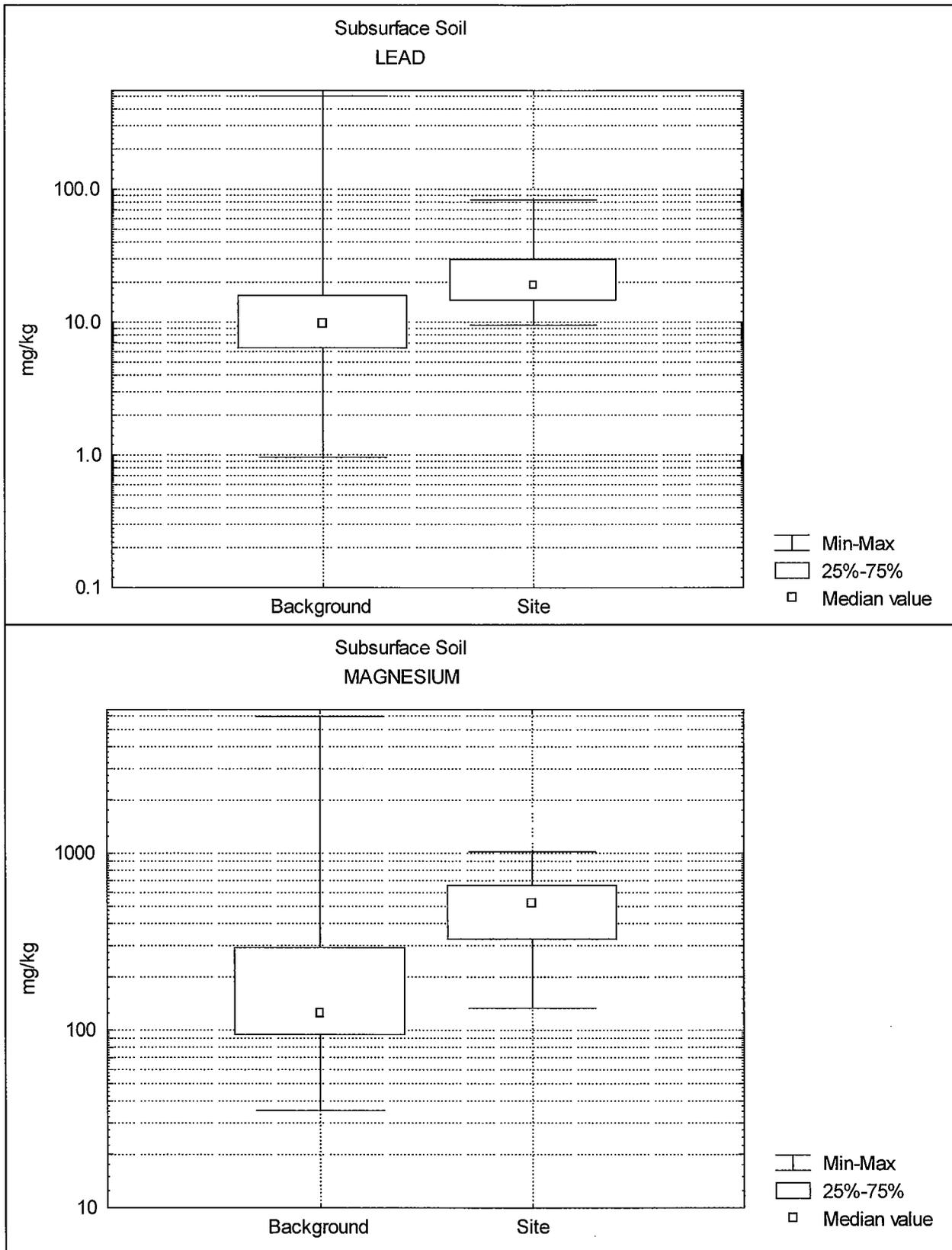


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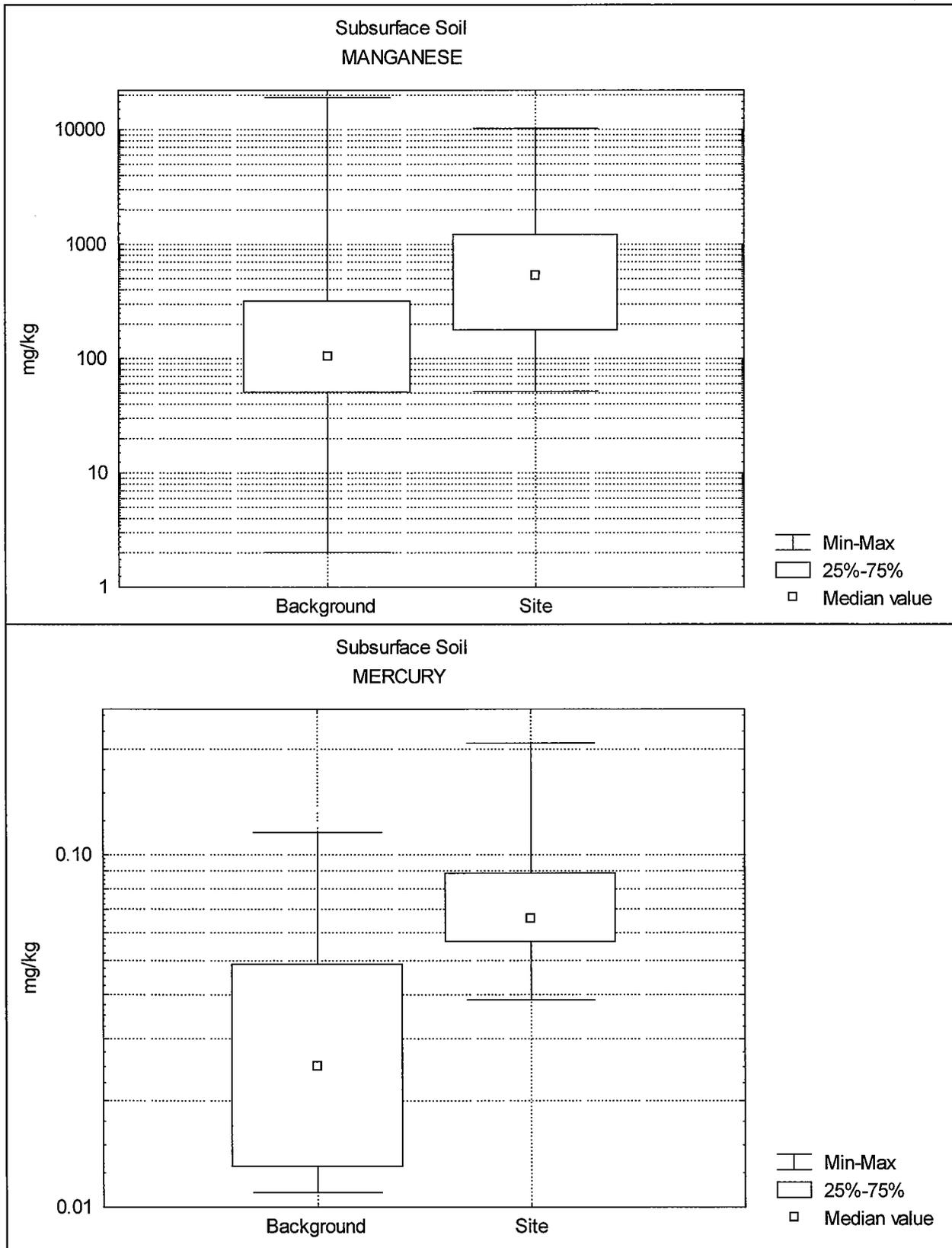


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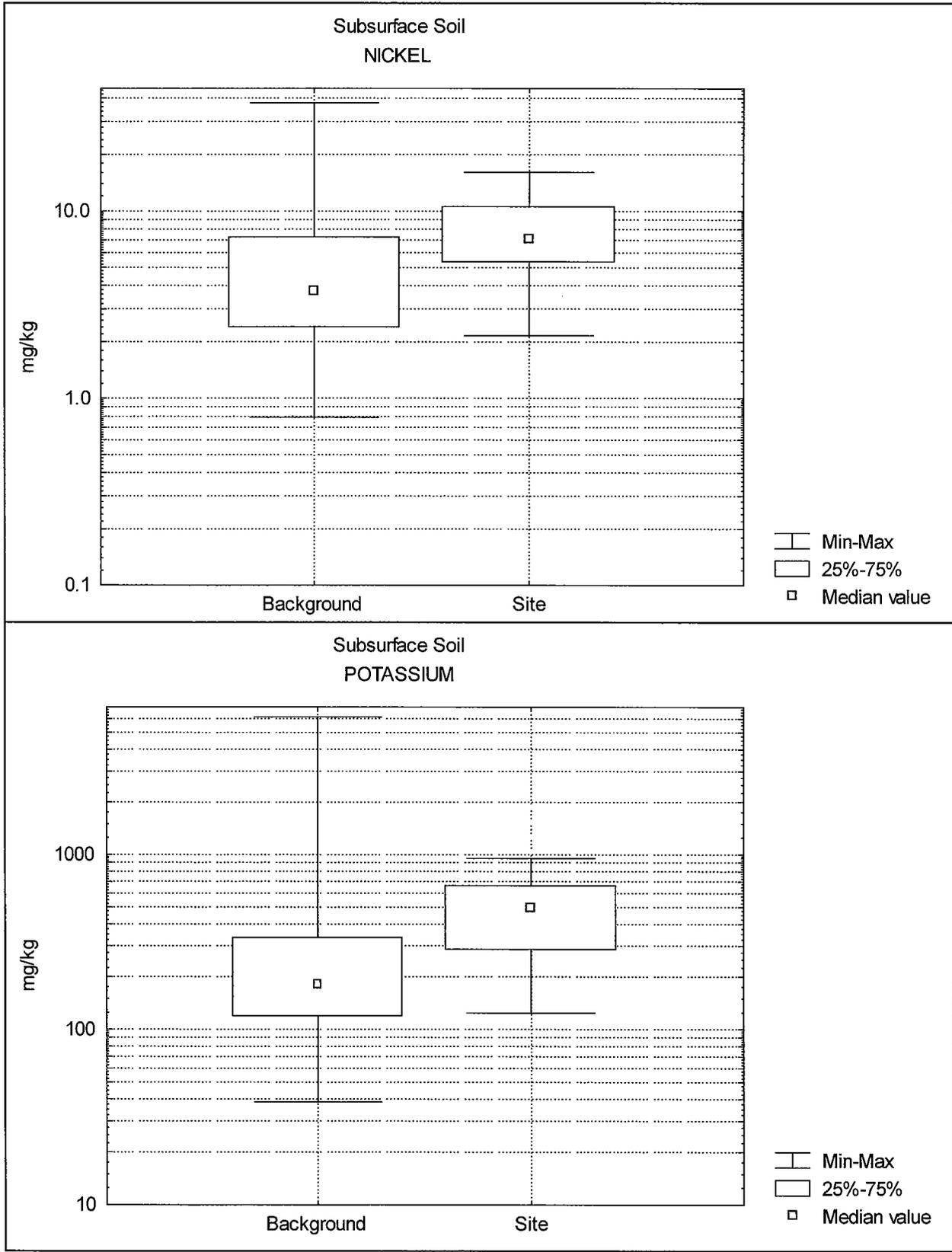


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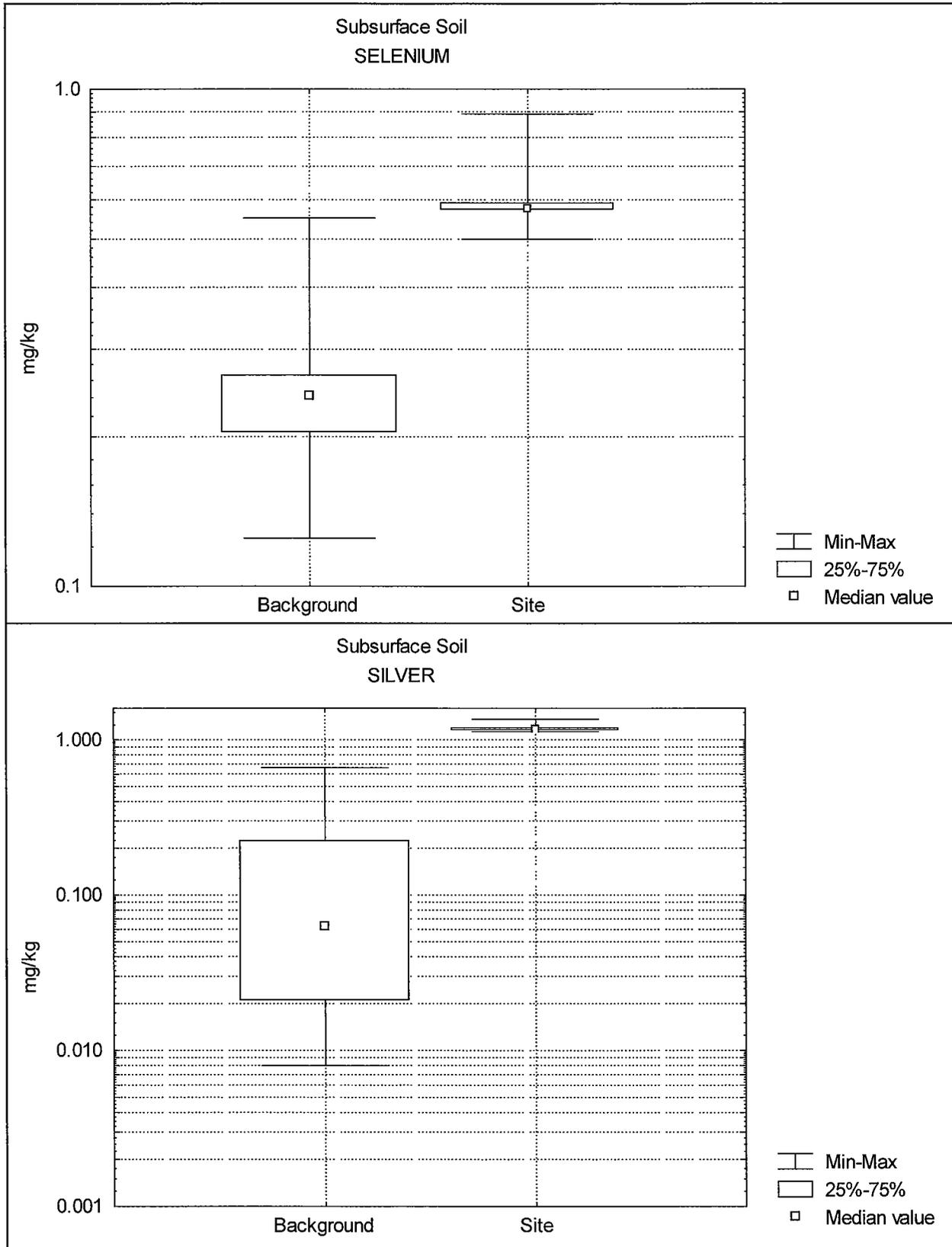


Figure 1-16

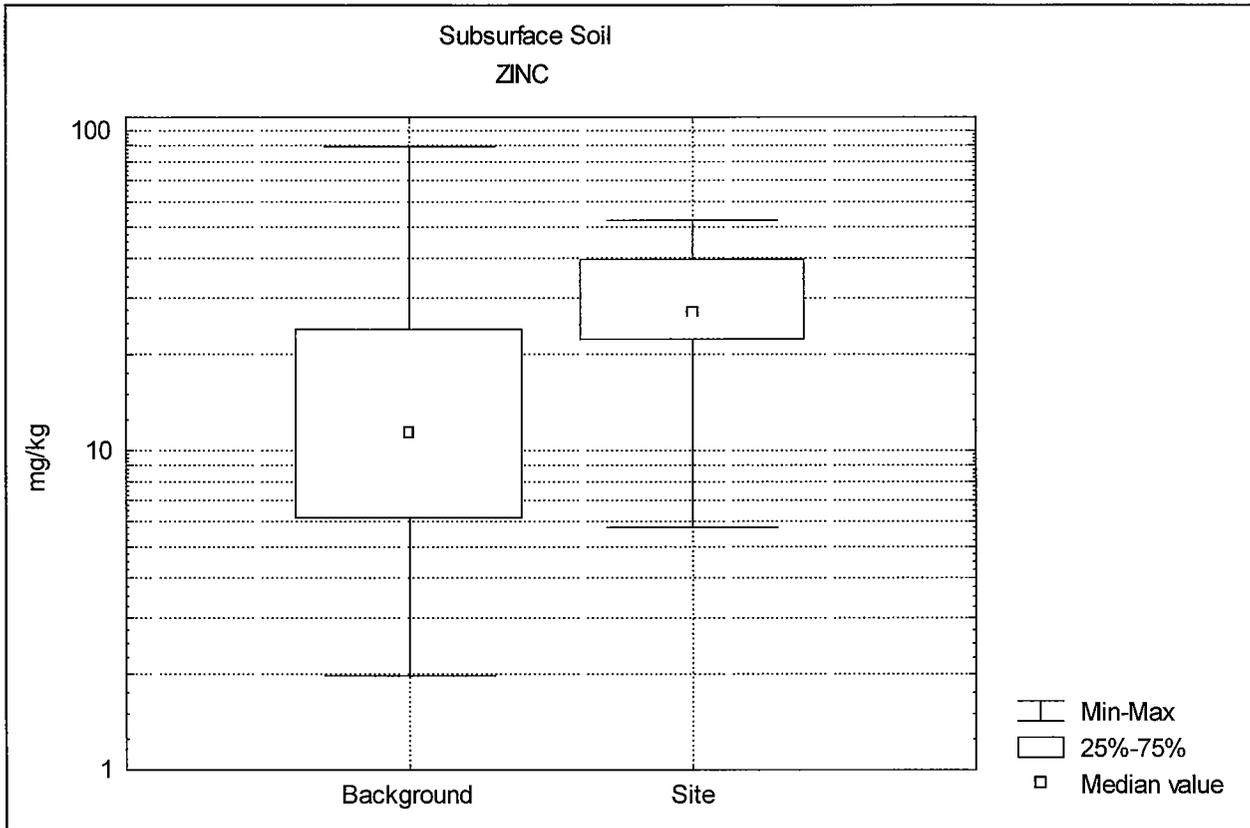


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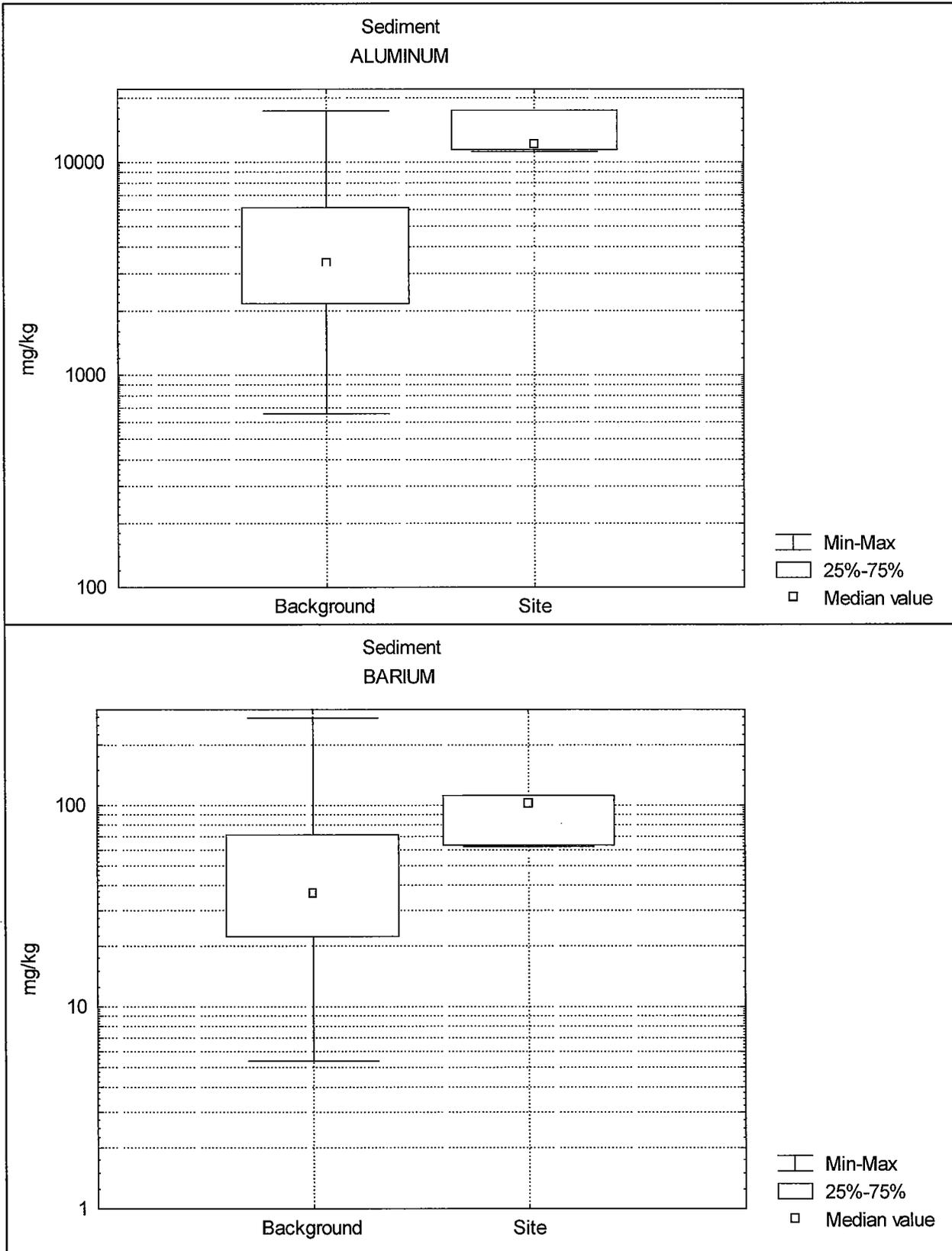


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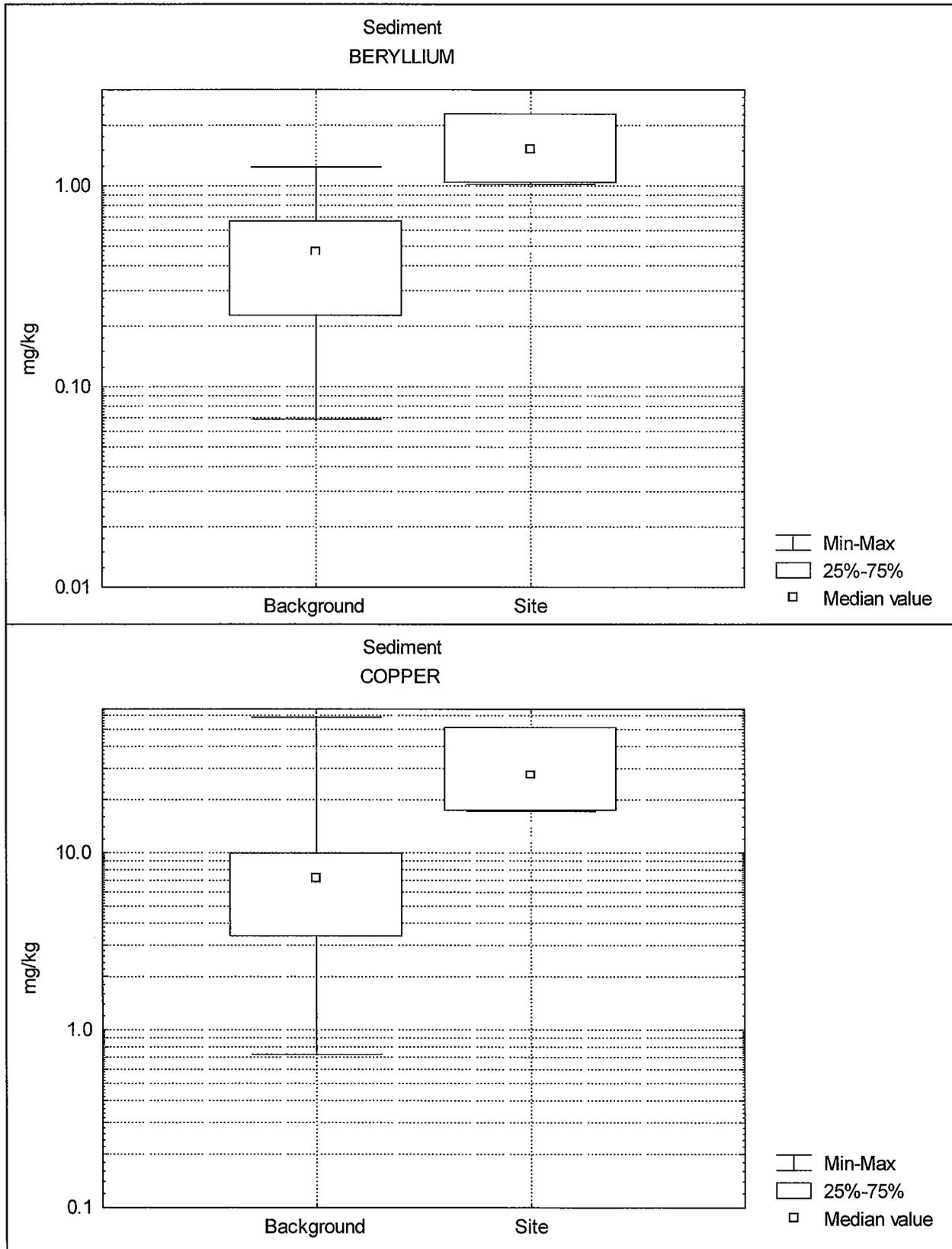


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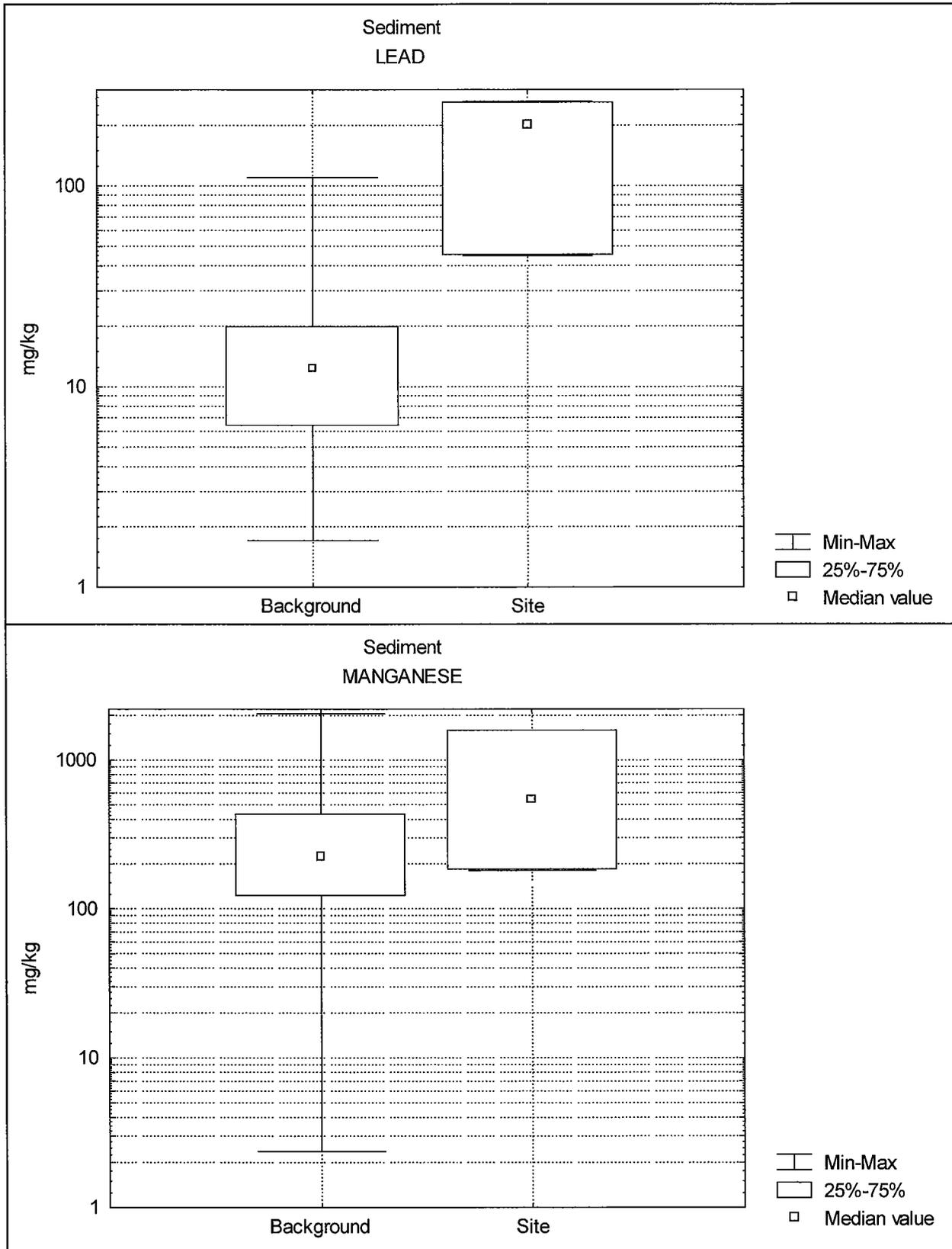
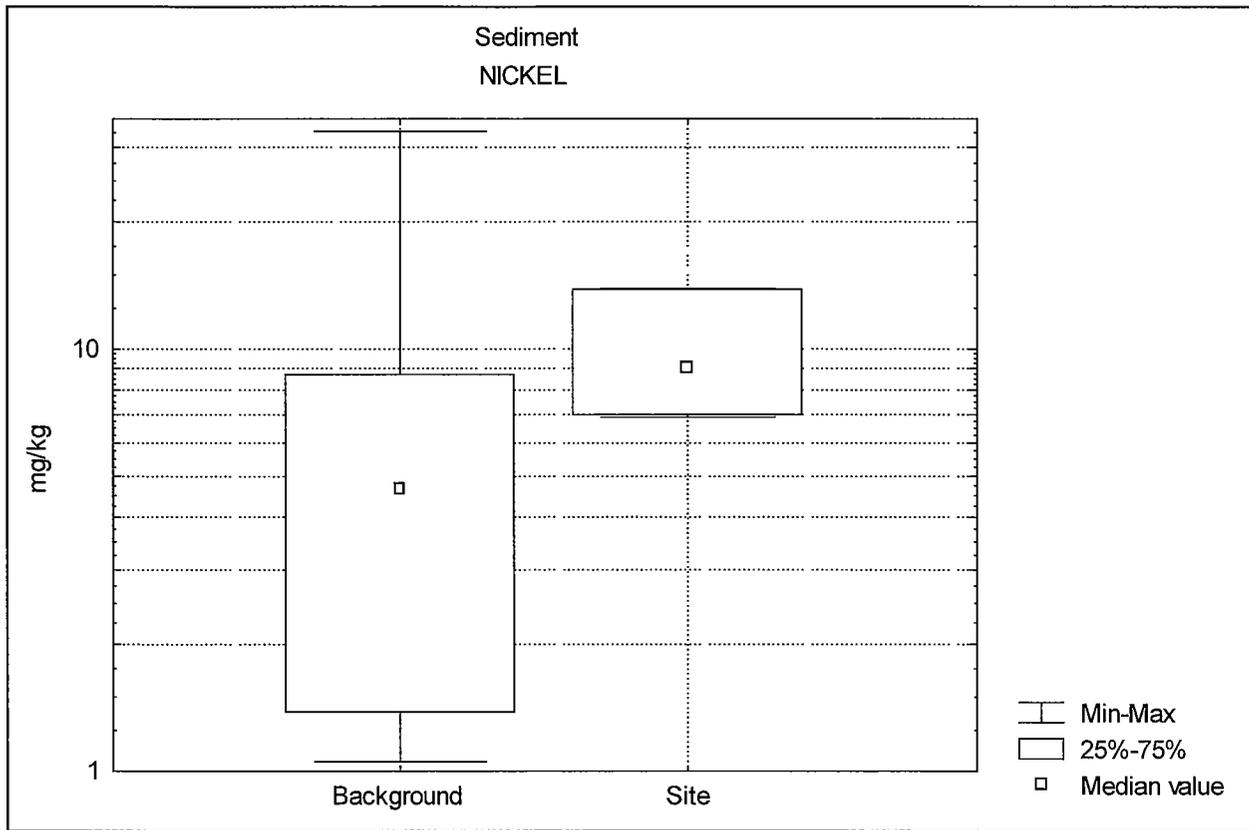


Figure 1-20



GEOCHEMICAL

Geochemical Evaluation of Metals in Soil and Sediment Former Rifle/Machine Gun Ranges, Parcels 100Q and 101Q Fort McClellan, Alabama

1.0 Introduction

This report provides the results of a geochemical evaluation of inorganic constituents in soil and groundwater samples from the Former Rifle/Machine Gun Ranges (Firing Line Areas), Parcels 100Q and 101Q, Fort McClellan, Calhoun County, Alabama. Sixteen elements in soil and four elements in sediment failed statistical comparison to background. A geochemical evaluation was performed to determine if the elevated concentrations are naturally occurring or if they contain a component of contamination.

Site samples included in the evaluations consist of 21 surface soil samples (0 to 1 foot below ground surface [bgs]) collected in January and February 2002, 21 subsurface soil samples (3 to 4 feet bgs) collected in January and February 2002, and 3 sediment samples collected in February 2002. All of the site samples were analyzed for the full list of 23 target analyte list (TAL) metals. Installation-wide background data for TAL metals in soil, sediment, groundwater, and surface water are provided in the background study report (Science Applications International Corporation, 1998) and are used in the following evaluations.

2.0 Geochemical Evaluation Methodology

Naturally occurring trace element concentrations in environmental media commonly exceed regulatory screening criteria. For example, trace element distributions in uncontaminated soil tend to have very large ranges (two to three orders of magnitude are not uncommon), and are highly right-skewed, resembling lognormal distributions. These trace elements are naturally associated with specific soil-forming minerals, and the preferential enrichment of a sample with these minerals will result in elevated trace element concentrations. It is thus important to be able to identify these naturally high concentrations and distinguish them from potential contamination.

If an analyte fails statistical comparison to background as described in the “Statistical Comparison of Site and Background Data for the Firing Line Areas, Parcels 100Q and 101Q,” then a geochemical evaluation is performed to determine if the elevated concentrations are caused by natural processes. The importance of geochemical evaluations in distinguishing between site and background data sets has been recognized in the industry (U.S. Environmental

Protection Agency, 1995; Barclift, *et al.*, 2000; U.S. Navy, 2002; Myers and Thorbjornsen, 2004). When properly evaluated, geochemistry can provide mechanistic explanations for apparently high, yet naturally occurring, constituents. Anomalous samples that may represent contamination can also be readily distinguished from uncontaminated samples. This section describes the geochemical evaluation techniques that were employed in the Parcels 100Q and 101Q site-to-background comparisons.

It should be noted that the geochemical evaluations rely in part on professional judgment and qualitative assessment is a necessary part of the process. Samples that plot off the linear trend on a correlation plot are certainly suspect, but because all uncertainty cannot be eliminated from the evaluation, such plots cannot be construed as definitive proof of contamination. However, anomalous samples should be flagged as suspect and their results used as a basis for further investigation, risk assessment, or remediation, as appropriate. The combination of statistical evaluations (Tiers 1 and 2) and geochemical evaluation (Tier 3) as presented in this appendix is effective in reducing the occurrences of decision errors relative to consideration of statistics or geochemistry alone.

Soil and Sediment. The geochemical evaluation is based on the natural associations of trace elements with specific minerals in the soil or sediment matrix. As an example, arsenic in most uncontaminated oxic soils is almost exclusively associated with iron oxide minerals (Bowell, 1994; Schiff and Weisberg, 1997). (The term “iron oxide” is used here to include oxides, hydroxides, oxyhydroxides, and hydrous oxides of iron.) This association of arsenic with iron oxides is a result of the adsorptive behavior of this particular trace metal in an oxic soil environment. Arsenic is present in oxic soil pore fluid as negatively charged oxyanions (HAsO_4^- , H_2AsO_4^-) (Brookins, 1988). These anions have strong affinities to adsorb on the surfaces of iron oxides, which maintain a strong positive surface charge (Electric Power Research Institute, 1986). If a soil sample has a high percentage of iron oxides, then it is expected to have a proportionally higher concentration of arsenic.

The absolute concentrations of arsenic and iron can vary by several orders of magnitude at a site, but the arsenic/iron ratios in the samples are usually quite constant as long as no contamination is present (Daskalakis and O'Connor, 1995). If a sample has some naturally occurring arsenic plus additional arsenic from an herbicide or some other source, then it will have an anomalously high ratio relative to the other uncontaminated samples. These ratios thus serve as a powerful technique for identifying contaminated samples.

The evaluation includes the generation of plots in which detected arsenic concentrations in a set of samples are plotted on the y-axis, and the corresponding detected iron concentrations are plotted on the x-axis. The slope of a best-fit line through the samples is equal to the average arsenic/iron background ratio. If the samples with the highest arsenic concentrations plot on the same linear trend as the other samples, then it is most probable that the elevated concentrations are natural, and are caused by the preferential enrichment of iron oxides in those samples. If the site samples with elevated arsenic concentrations plot above the trend displayed by the uncontaminated samples, then there is evidence that those samples have an excess contribution of arsenic, and contamination may be indicated.

Each trace element is associated with one or more minerals in the soil matrix. Vanadium and selenium, along with arsenic, form anionic species in solution and are associated with iron oxides, which maintain a positive surface charge. Divalent metals such as barium, cadmium, lead, and zinc tend to form cationic species in solution and are attracted to clay mineral surfaces, which maintain a negative surface charge. These trace elements would be evaluated against aluminum, which is a major component of clay minerals. Manganese oxides also have an affinity to adsorb divalent cations such as barium, cobalt, and lead (Kabata-Pendias, 2001). These trace elements would be evaluated against manganese.

3.0 Results of the Geochemical Evaluation for Multiple Elements in Soil

This section presents the results of the geochemical evaluation of aluminum, barium, beryllium, cobalt, copper, iron, lead, magnesium, manganese, mercury, nickel, potassium, selenium, silver, vanadium, and zinc in soil samples from Parcels 100Q and 101Q. Correlation plots are provided in Attachment 1.

Aluminum

Aluminum is the second most abundant element analyzed in the Parcel 100(Q)-101(Q) soil samples, with a mean concentration of 16,252 mg/kg (1.6 weight percent). Aluminum is a primary component of common soil-forming minerals such as clays, feldspars, and micas. Aluminum also substitutes for ferric iron in iron oxide minerals, and can adsorb on iron oxide surfaces (Cornell and Schwertmann, 2003). Iron is the most abundant element analyzed in the site soil samples, and is mostly present as iron oxides, which are common soil-forming minerals. Clays and iron oxides tend to exist as very fine particles, so both aluminum and iron are enriched in samples with finer grain sizes. The site soil boring logs note that the predominant soil types in the sampled intervals are clay and silt with some clay, which indicates that the site samples contain a high percentage of fine-grained material.

A plot of aluminum versus iron concentrations can be as a qualitative indicator of the relative abundance of clay and iron oxide minerals in site soil (Figure 1). Site surface soil samples are represented by open triangles, site subsurface soil samples by filled triangles, and background soil samples by filled circles. For both soil intervals, the site samples exhibit higher aluminum concentrations than many of the background samples, but they also contain proportionally higher iron and lie on the background trend (Figure 1), indicating that the Al/Fe ratios in the site and background samples are roughly equal. This suggests that the site samples are naturally enriched in clays and iron oxides relative to the background samples, and that the aluminum is natural. It is important to note that clays and iron oxides adsorb specific trace elements (as discussed in Section 2.0), so samples that plot on the upper end of the trend in Figure 1 are expected to contain proportionally higher concentrations of trace elements.

Conclusion

Aluminum detected in the site soil samples is naturally occurring.

Barium

Manganese oxides have an affinity to adsorb divalent cations such as barium and cobalt (Kabata-Pendias, 2001). If a soil sample contains a high proportion of manganese oxides, then it is expected to contain high concentrations of manganese and associated trace elements. The site and background samples form a collinear trend in a plot of barium versus manganese (Figure 2). The site samples with the highest barium concentrations also contain the highest manganese concentrations, and lie on the trend established by the other samples. These observations indicate that barium in the site samples is associated with manganese oxides at a relatively constant ratio, and is natural.

Conclusion

Barium detected in the site soil samples is naturally occurring.

Beryllium

A plot of beryllium versus manganese is provided in Figure 3. The site and background samples form a common linear trend with a positive slope. The site samples that have the highest beryllium concentrations also have the highest manganese, and lie on the trend established by the other samples. Beryllium in the site samples is associated with manganese oxides at a relatively constant ratio, and is natural.

Conclusion

Beryllium detected in the site soil samples is naturally occurring.

Cobalt

Manganese oxides have an affinity to adsorb divalent cations such as barium and cobalt (Kabata-Pendias, 2001). If a soil sample contains a high proportion of manganese oxides, then it is expected to contain high concentrations of manganese and associated trace elements. A plot of cobalt versus manganese reveals a strong linear trend with a positive slope for the site and background samples (Figure 4). The site samples with the highest cobalt concentrations also contain proportionally higher manganese, and lie on the linear trend. Cobalt in the site samples is associated with manganese oxides at a relatively constant ratio, and is natural.

Conclusion

Cobalt detected in the site soil samples is naturally occurring.

Copper

Copper in soil has an affinity to adsorb on the surfaces of minerals such as clays and iron oxides (Kabata-Pendias, 2001). The site and background samples form a common linear trend with a positive slope in a plot of copper versus aluminum (Figure 5). The site samples with high copper concentrations also exhibit proportionally higher aluminum, and lie on the background trend. Copper in these samples has a natural source.

Conclusion

Copper detected in the site soil samples is naturally occurring.

Iron

Iron is the most abundant of the 23 elements analyzed in the site soil samples, with a mean concentration of 23,039 mg/kg (2.3 weight percent). Iron oxides are common soil-forming minerals, and occur as discrete mineral grains or as coatings on silicate minerals. Aluminum is a primary component of other common soil-forming minerals such as clays, feldspars, and micas, and also substitutes for ferric iron in iron oxides. Clays and iron oxides tend to exist as very fine particles, so both aluminum and iron are enriched in samples with finer grain sizes. A plot of aluminum versus iron concentrations can be used to qualitatively assess the relative abundance of these minerals in site soil (Figure 1). For both soil intervals, the site samples exhibit higher iron concentrations than many of the background samples, but they contain proportionally higher aluminum and lie on the general background trend. This suggests that the site samples are naturally enriched in clays and iron oxides relative to the background samples, and that the iron is natural. It is important to note that iron oxides and clays adsorb specific trace elements (as discussed in Section 2.0), so samples that plot on the upper end of the trend in Figure 1 are expected to contain proportionally higher concentrations of trace elements.

Conclusion

Iron detected in the site soil samples is naturally occurring.

Lead

Manganese oxides in soil have a strong affinity to adsorb divalent cations such as barium and lead (Kabata-Pendias, 2001). Samples that contain a high percentage of manganese oxides will contain elevated manganese concentrations and proportionally higher lead. A common linear trend with a positive slope is observed for the background samples and most of the site samples in a plot of lead versus manganese (Figure 6). Lead in these samples is associated with manganese oxides at a relatively constant ratio, and is natural. There are four site surface samples, however, that contain high lead but only moderate manganese and which lie above the trend formed by the other samples. These samples contain excess lead beyond that which can be explained by the manganese content, and most likely contain a component of contamination: PY0003 (sample location HR-100Q-GP02), PY0027 (HR-100Q-GP13), PY0029 (HR-100Q-GP14), and PZ0001 (HR-101Q-GP01).

Conclusion

Lead concentrations in surface soil samples PY0003, PY0027, PY0029, and PZ0001 are anomalously high relative to the major elements, and most likely contain a component of contamination. Lead detected in the other site soil samples is naturally occurring.

Magnesium

Magnesium is a common component of minerals such as clays and micas, which contain aluminum as a primary constituent. A plot of magnesium versus aluminum reveals a generally linear trend for most of the background samples (Figure 7). The site samples are highly linear ($R^2 = 0.86$ and 0.89 for the surface and subsurface intervals, respectively); the samples with the highest magnesium also exhibit the highest aluminum content, and lie on the background trend. These observations indicate that magnesium in the site samples is associated with aluminum-bearing minerals at a nearly constant ratio, and is natural.

Conclusion

Magnesium detected in the site soil samples is naturally occurring.

Manganese

As discussed previously, manganese oxides are common in soil and have an affinity to adsorb specific trace elements such as barium and cobalt. A positive correlation is thus expected between manganese and associated trace elements in uncontaminated soil samples. The strongly linear correlations between barium and manganese (Figure 2) and cobalt and manganese (Figure 4), and the absence of outliers plotting off the linear trends on these correlation plots, indicate a natural source for these three elements (Figure 2).

Conclusion

Manganese detected in the site soil samples is naturally occurring.

Mercury

Mercury concentrations in soil are commonly controlled through organic complex formation (Kabata-Pendias, 2001), so poor correlations between mercury and iron or mercury and aluminum are often observed, even in uncontaminated soil samples. A plot of mercury versus aluminum is provided in Figure 8. All of the site samples lie on the general background trend, indicating that the mercury in these samples is associated with clays at ratios consistent with those of the background samples, and is natural.

Conclusion

Mercury detected in the site soil samples is naturally occurring.

Nickel

Nickel is commonly associated with clays in soils (Kabata-Pendias, 2001). A plot of nickel versus aluminum reveals a generally linear trend with a positive slope for the background samples (Figure 9). The site samples are highly linear ($R^2 = 0.90$ and 0.74 for the surface and subsurface intervals, respectively) and lie on the background trend. This indicates that nickel in the site samples is associated with clays at a nearly constant ratio, and is natural.

Conclusion

Nickel detected in the site soil samples is naturally occurring.

Potassium

Potassium is a major element that is a common constituent of minerals such as clays, which also contain aluminum. Most of the background samples form a generally linear trend in a plot of potassium versus aluminum, and the site samples lie on this trend (Figure 10). The site samples with the highest potassium also have proportionally higher aluminum and lie on the trend established by the other samples. This indicates that potassium in the site samples is associated with clays and other aluminum-bearing minerals at a relatively constant ratio, and that the potassium is natural.

Conclusion

Potassium detected in the site soil samples is naturally occurring.

Selenium

As explained in Section 2.0, selenium has a strong affinity to adsorb on iron oxides in oxic soils, so a positive correlation between selenium and iron is expected for uncontaminated soil samples. Comparison to background is hindered because of the high percentage of nondetects in the background data set. However, a plot of selenium versus iron reveals a linear trend with a positive slope for most of the site samples, and one of the two background samples with detectable selenium lies on this trend (Figure 11). There is one site subsurface sample (PY0034, with an estimated concentration of 0.892 mg/kg Se) that exhibits a slightly higher Se/Fe ratio than the other site samples and that lies slightly above the linear trend. There is a background sample, however, that contains a higher selenium concentration (1.28 mg/kg) and a similarly elevated Se/Fe ratio. It is likely that these two samples reflect the natural variability in Se/Fe ratios in Ft. McClellan soils. It is important to note that the site selenium detections are all estimated concentrations below the reporting limit, and the uncertainty associated with such values may explain the slightly high Se/Fe ratio observed in sample PY0034. All of these observations indicate that selenium in the site samples is associated with iron oxides at ratios consistent with those of the background samples, and is natural.

Conclusion

Selenium detected in the site soil samples is naturally occurring.

Silver

A plot of silver versus aluminum is provided in Figure 12. The eight site samples with detectable silver have higher concentrations most of the background samples, but they also have higher aluminum concentrations. This suggests that these site samples are preferentially enriched in clay minerals and associated trace elements, and that the silver is natural. It is important to note that all eight site detections are estimated values (ranging from 1.13 J to 1.36 J mg/kg, with a mean of 1.22 mg/kg) below the reporting limit, and that such values are highly uncertain. In comparison, the background detections are mostly unestimated concentrations ranging from 0.019 to 1.87 mg/kg, with a mean of 0.151 mg/kg (14 of the 82 background samples are estimated values). Additionally, the site samples are characterized by higher reporting limits relative to the background samples: the site reporting limits range from 2 to 2.69

mg/kg, with a mean of 2.27 mg/kg, whereas the reporting limits for the background nondetects range from 0.016 to 1.2 mg/kg, with a mean of 0.293 mg/kg [reporting limit data are unavailable for the background detected concentrations]. The uncertainty associated with the estimated site concentrations, combined with the difference in reporting limits between the data sets, likely explains why the site samples do not exhibit the same Ag/Al ratios exhibited by the background samples.

Conclusion

Silver detected in the site soil samples is naturally occurring.

Vanadium

As discussed in Section 2.0, vanadium has a strong affinity to adsorb on iron oxides in oxic soils, so a positive correlation between vanadium and iron is expected for uncontaminated samples under those conditions. A plot of vanadium versus iron reveals a strong collinear trend for the site and background samples ($R^2 = 0.91$ and 0.60 for the site surface and subsurface intervals, respectively) (Figure 13). The site samples exhibit higher vanadium concentrations than many of the background samples, but they also contain proportionally higher iron and lie on the background trend. These observations indicate that vanadium in the site samples is associated with iron oxides at a nearly constant ratio, and is natural.

Conclusion

Vanadium detected in the site soil samples is naturally occurring.

Zinc

Zinc in soil has an affinity for multiple sorptive surfaces, including clays, iron oxides, and manganese oxides (Kabata-Pendias, 2001). A plot of zinc versus aluminum is provided in Figure 14. The site and background samples form a common linear trend with a positive slope. The site samples with the highest zinc also contain proportionally higher aluminum, and lie on the trend established by the other samples. This indicates that zinc in the site samples is associated with clays and other aluminum-bearing minerals at a relatively constant ratio, and is natural.

Conclusion

Zinc detected in the site soil samples is naturally occurring.

4.0 Results of the Geochemical Evaluation for Multiple Elements in Sediment

This section presents the results of the geochemical evaluation of aluminum, beryllium, copper, and lead in sediment samples from Parcels 100Q and 101Q. Correlation plots are provided in Attachment 1.

Aluminum

Aluminum is the second most abundant element analyzed in the Parcel 100(Q)-101(Q) sediment samples, with a mean concentration of 13,567 mg/kg (approximately 1.4 weight percent). Aluminum is a primary component of minerals such as clays, feldspars, and micas. Aluminum

also substitutes for ferric iron in iron oxide minerals, and can adsorb on iron oxide surfaces (Cornell and Schwertmann, 2003). Iron is the most abundant element analyzed in the site sediment samples (mean concentration of 17,433 mg/kg; 1.7 weight percent), and is mostly present as iron oxides, which are common minerals in soil and sediment. Clays and iron oxides tend to exist as very fine particles, so both aluminum and iron are enriched in samples with finer grain sizes.

A plot of aluminum versus iron concentrations can be as a qualitative indicator of the relative abundance of clay and iron oxide minerals in site sediment (Figure 15). Site sediment samples are represented by filled triangles and background sediment samples are represented by filled circles. The site samples exhibit higher aluminum concentrations than most of the background samples, but they also contain proportionally higher iron and lie on the background trend, indicating that the Al/Fe ratios in the site and background samples are roughly equal. This suggests that the site samples are naturally enriched in clays and iron oxides relative to the background samples, and that the aluminum is natural. It is important to note that clays and iron oxides adsorb specific trace elements (as discussed in Section 2.0), so samples that plot on the upper end of the trend in Figure 15 are expected to contain proportionally higher concentrations of trace elements.

Conclusion

Aluminum detected in the site sediment samples is naturally occurring.

Beryllium

Beryllium can substitute for aluminum in minerals (Kabata-Pendias, 2001), and also has an affinity to adsorb on clay surfaces, so a positive correlation between beryllium and aluminum would be expected for uncontaminated samples. A plot of beryllium versus aluminum is provided in Figure 16. The site and background samples form a common linear trend with a positive slope. The three site samples contain higher beryllium concentrations than most of the background samples, but they also contain proportionally higher aluminum. These observations indicate that beryllium in the samples is associated with aluminum-bearing minerals at a relatively constant ratio, and is natural.

Conclusion

Beryllium detected in the site sediment samples is naturally occurring.

Copper

Copper has an affinity to adsorb on the surfaces of minerals such as clays and iron oxides (Kabata-Pendias, 2001). The background samples form a generally linear trend with a positive slope in a plot of copper versus aluminum (Figure 17). The site samples have higher copper concentrations than most of the background samples, but they also exhibit proportionally higher aluminum and lie on the background trend. Copper in these samples has a natural source.

Conclusion

Copper detected in the site sediment samples is naturally occurring.

Lead

As discussed in Section 2.0, divalent metals such as lead tend to form cationic species in solution and are attracted to clay mineral surfaces, which maintain a negative surface charge. The background samples form a weak linear trend in a plot of lead versus aluminum (Figure 18). One of the site samples lies on the background trend, but the other two site samples contain high lead but only moderate aluminum (as well as moderate iron and manganese) and lie above the background trend. The anomalously high Pb/Al ratios of samples PY1001 (sample location HR-100Q-SW/SD01) and PY1004 (HR-100Q-SW/SD03) may reflect a component of contamination.

Conclusion

Lead concentrations in site sediment samples PY1001 and PY1004 are anomalously high relative to the major elements and may contain a component of contamination.

5.0 Summary

This section summarizes the results of the geochemical evaluations of selected inorganics in soil and sediment samples from Parcels 100Q and 101Q.

Soil. Geochemical evaluation indicates that all of the aluminum, barium, beryllium, cobalt, copper, iron, lead, magnesium, manganese, mercury, nickel, potassium, selenium, silver, vanadium, and zinc concentrations detected in the surface and subsurface soil samples are naturally occurring. Four surface soil samples have anomalously high lead concentrations that may contain a component of contamination: PY0003 (sample location HR-100Q-GP02), PY0027 (HR-100Q-GP13), PY0029 (HR-100Q-GP14), and PZ0001 (HR-101Q-GP01). All of the lead concentrations detected in the subsurface soil samples are naturally occurring.

Sediment. Geochemical evaluation indicate that detected concentrations of aluminum, beryllium, and copper in the sediment samples are naturally occurring. The lead concentrations in samples PY1001 (sample location HR-100Q-SW/SD01) and PY1004 (sample location HR-100Q-SW/SD03) are anomalously high relative to the reference element concentrations, and may contain a component of contamination.

6.0 References

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ATTACHMENT 1

